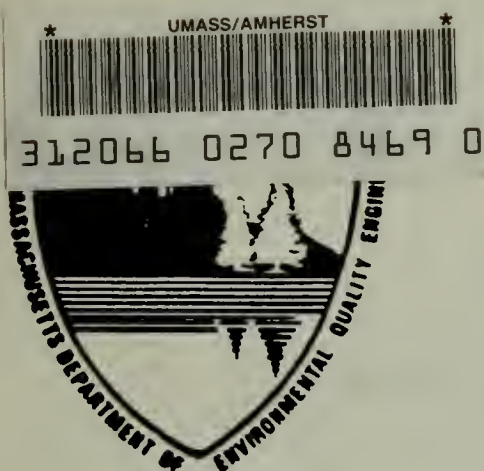


MASS. EA23.2:G91/2



Commonwealth of Massachusetts
Department of Environmental Quality Engineering
Division of Water Supply

GROUNDWATER MONITORING HANDBOOK

GOVERNMENT DOCUMENTS
COLLECTION

JAN 03 1989

University of Massachusetts
Depository Copy

July 1984

Reprinted April 1985

Michael Dukakis
Governor

James S. Hoyte
Secretary

S. Russell Sylva
Commissioner, DEQE

PUBLICATION: #13,994-152-80-4-85-CR
Approved by Daniel Carter, State Purchasing Agent

Second Printing 8/85

GROUNDWATER MONITORING HANDBOOK

Prepared by the

DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING

DIVISION OF WATER SUPPLY

WATER SUPPLY PLANNING AND PROGRAM DEVELOPMENT SECTION

July 1984

ACKNOWLEDGEMENTS

Anthony D. Cortese, Sc.D., Commissioner, DEQE
M. Ilyas Bhatti, P.E., Director
Division of Water Supply
David Y. Terry, Director
Water Supply Planning and Program Development Section

Authors

Steven P. Roy, Groundwater Programs Manager
Paula Milner, Principal Planner
Denis D'Amore, Ph.D., Hydrogeologist
John Drake, Hydrogeologist
Elaine C. White, Head Clerk

This report was prepared with partial funding from the United States EPA Clean Water Act, Sections 208 and 205(j). The use of brand or trade names or commercial products within this document does not constitute endorsement.

TABLE OF CONTENTS

INTRODUCTION

	<u>Page</u>
CHAPTER 1. Purpose of Groundwater Monitoring	2
WHY MONITOR PUBLIC GROUNDWATER SUPPLIES?	2
ESTABLISHING GROUNDWATER MONITORING OBJECTIVES	5
PROBLEMS IN THE DESIGN OF GROUNDWATER MONITORING SYSTEMS	8
VARIABILITY IN GROUNDWATER QUALITY DATA	9
CHAPTER 2. Hydrogeological Investigations: The Basis for Con- ducting a Sound Groundwater Monitoring Program	15
TOOLS AND TECHNIQUES FOR DEFINING SITE HYDROGEOLOGY..	16
Field Reconnaissance	16
Surface Geophysics	17
1. Direct Current Resistivity Method	18
2. Electromagnetic Terrain Conductivity Method	20
3. Seismic Refraction	21
4. Ground Penetrating Radar	22
5. Gravimetry	23
6. Magnetic Surveys	23
Summary of Geophysical Methods	24
Remote Sensing	29
1. Aerial Photography	29
2. Side Looking Airborne Radar	29
3. Landsat	30
CHAPTER 3. Construction of Monitoring Wells	31
GENERAL INFORMATION	31
DRILLING METHODS	34

	<u>Page</u>
CHAPTER 3	
(Continued)	
1. Solid-Stem Continuous-Flight Auger	34
2. Hollow-Stem Continuous-Flight Auger	35
3. Keck Screened, Hollow-Stem, Continuous- Flight Auger	37
4. Bucket Auger	39
5. Jetting	40
6. Drive Points	41
7. Mud Rotary	41
8. Air Rotary	43
9. Air Drilling with Casing Hammer	44
10. Cable Tool	46
11. Reverse Circulation	48
12. Special Reverse Circulation	49
USE OF BOREHOLE GEOPHYSICS	52
1. Spontaneous-Potential Logs	52
2. Normal Resistivity Logs	52
3. Natural-Gamma Logs	52
4. Gamma-Gamma Logs	52
5. Caliper Logs	52
6. Temperature Logs	53
7. Fluid-Conductivity Logs	53
CHAPTER 4	
Monitoring in the Unsaturated Zone	55
RESISTIVITY METHODS	55
SOIL WATER SAMPLING METHODS	55
1. Vacuum Lysimeter	56
2. Pressure-Vacuum Lysimeter	57
3. Deep Pressure-Vacuum Lysimeter	59
4. Organic Compound Sampler	60
5. Hollow Fiber Sampler	60
6. Membrane Filter Sampler	62
CHAPTER 5.	
Monitoring in the Saturated Zone	63
SPECIFIC REQUIREMENTS FOR MONITORING WELLS	63
1. Location	63
2. Diameter	64
3. Depth	64
4. Intake Portion of Monitoring Wells	65
5. Well Casings	65
6. Cross Contamination Prevention During Drilling .	66

	<u>Page</u>
CHAPTER 5	
(Continued)	
MONITORING WELL DEVELOPMENT	67
1. Surge Block	67
2. Air Lift	68
3. Bailer	68
4. Surging By Pumping	68
OBSERVATION WELLS	69
MONITORING WELLS	69
PROCEDURES AND TECHNIQUES FOR MONITORING WELL INSTALLATION	69
USE OF FIELD TESTING EQUIPMENT	69
FIELD TECHNIQUES FOR LOCATING SCREENS	81
FINISHING MONITORING WELLS	81
OBSERVATION AND MONITORING WELL CONSTRUCTION	81
1. Well Screen Packing	81
2. Grouting	83
3. Protection of Wells	83
4. Documentation of Drilling Information	83
GENERAL GROUNDWATER MONITORING REQUIREMENTS	85
MONITORING WELL AND TEST HOLE ABANDONMENT	85
WATER SAMPLING FOR GROUNDWATER MONITORING	87
Flushing Monitoring Wells	87
COLLECTING WATER SAMPLES	87
1. Bailers	87
2. Pitcher Pump	88
3. Air Lift Pump	88
4. Shallow Well Centrifugal Pump On Suction Pipe ..	89
5. Centrifugal-Jet Pump	89
6. Submersible Pump	89
7. Tube Pump	90
PREVENTION OF CROSS CONTAMINATION DURING SAMPLING	90
MONITORING PARAMETERS	90
FREQUENCY OF SAMPLING	104

	<u>Page</u>
CHAPTER 5	
(Continued)	
REPORTING OF SAMPLING RESULTS	104
LABORATORY METHODS	106
PRESERVATION METHODS AND HOLDING TIME	106
QUALITY CONTROL	106
SOIL SAMPLING PROCEDURES	107
COLLECTING SOIL SAMPLES	107
FIELD HANDLING OF SAMPLES	107
1. Extracting and Storing Soil Water	107
2. Storing Soil Samples	107
3. Analyzing Soil Water	108
ANALYZING SOIL SAMPLES	108
1. Field Analysis	108
2. Undisturbed Soil Laboratory Analysis	108
3. Field Permeability Testing	108
SAMPLING STATISTICS	108
1. Sampling Techniques	108
2. Simple Random Sampling	109
3. Systematic Sampling	109
4. Stratified Random Sampling	110
APPENDICES	111
APPENDIX I : Chemical resistance of piping materials..	111
APPENDIX II : General groundwater monitoring requirements	127
APPENDIX III: Supplemental information on suitability of sampling methods, sources of bias and recommended sampling procedures	131
REFERENCES	141

LIST OF FIGURES

	<u>Page</u>
1. Groundwater resources in Massachusetts	4
2. Groundwater monitoring flow chart	7
3. Cyclical movement of chlorides in groundwater	12
4. Wenner, Lee - Partitioning and Schlumberger Electrode Arrays ...	19
5. Solid stem continuous flight auger	36
6. Keck screened, hollow stem, continuous flight auger	38
7. Mud rotary drilling	42
8. Air drilling with casing hammer	45
9. Cable tool drilling	47
10. Vacuum lysimeter	58
11. Pressure-vacuum lysimeter	58
12. Deep pressure vacuum lysimeter	61
13. Organic compound sampler	61
14. Monitoring well triangulation	70
15. Single level installation	72
16. Multiple piezometers in a single borehole	75
17. Gas-drive installations	77
18. Suction lift multilevel point sampler	79
19. Schematic diagram of a six-port multilevel assembly	80
20. Construction of a finished monitoring well	82
21. Soil sampling reporting form	86

LIST OF FIGURES (Continued)

	<u>Page</u>
22. Bailers	92
23. Depth specific bailer	93
24. Pneumatic depth specific sampler (syringe sampler)	95
25. Suction lift sampler	96
26. Gas squeeze pump	99
27. Gas lift sampler	100
28. Positive displacement gas driven pump	101
29. Destructive sampling methods	103
30. Chain of custody control	105

LIST OF TABLES

	<u>Page</u>
Table 1. Applications of geophysical methods to hazardous waste sites	25
Table 2. Characteristics of geophysical methods	26
Table 3. Typical applications of geophysical methods	27
Table 4. Susceptibility of geophysical methods to noise	28
Table 5. Comparison of drilling methods	32
Table 6. Advantages and disadvantages of commonly used drilling methods	50
Table 7. Advantages and disadvantages of the principle types of sampling installations	71
Table 8. Advantages and disadvantages of common backfilling materials	84
Table 9. Advantages and disadvantages of sample collection methods	91
Table A I-1 Chemical resistance of piping materials	112
Table A I-2 Chemical resistance chart	119
Table A I-3 Resistance of well casing thermoplastics to common materials under expected use conditions	125
Table A III-1 Suitability of sampling methods	132
Table A III-2 Potential sources of bias	134
Table A III-3 Summary of recommended sampling procedures	136
Table A III-4 Suitability of materials coming in contact with water samples	138

INTRODUCTION

This groundwater monitoring handbook was prepared for the Massachusetts Department of Environmental Quality Engineering by the Planning and Development Section of the Division of Water Supply. Its purpose is to provide Department staff with a variety of procedures and approaches for either developing and conducting a hydrogeological investigation or evaluating scopes of work submitted to the Department by consultants for review and approval.

The handbook is divided into five chapters. The first chapter discusses the need to establish monitoring objectives as well as some of the problems encountered in designing groundwater monitoring systems. Chapter 2 outlines the various tools and techniques available for defining site hydrogeology including field reconnaissance and surface geophysical and remote sensing methods. General information on monitoring well construction and a discussion of common drilling methods are presented in Chapter 3. Technology for monitoring in the unsaturated zone is presented in Chapter 4 and saturated zone monitoring is discussed in detail in Chapter 5 along with quality assurance and quality control procedures. Specific requirements for monitoring well construction and development can also be found here.

At the outset, it should be remembered that groundwater monitoring is an evolving science. Each situation requiring a monitoring program is unique for two reasons: 1) the geology of each site is always different; and (2) the physical, chemical and biological properties of the complete spectrum of contaminants are extremely variable. Modifications in instrumentation, sampling procedures, and field methodologies are constantly occurring. Consequently, personnel responsible for approving groundwater monitoring programs should be aware of the current state of the art as well as the basic principles of groundwater monitoring.

CHAPTER 1. PURPOSE OF GROUNDWATER MONITORING

Why Monitor Public Groundwater Supplies?

Groundwater is a very important source of water supply in Massachusetts. The Massachusetts Division of Water Resources estimates that approximately 35% of the population in the State relies upon groundwater for drinking purposes. This represents slightly more than 2 million people. To illustrate the importance of groundwater as a drinking source in Massachusetts, the map on the following page (Figure 1) reveals that 134 communities or 38% of the cities and towns in Massachusetts use groundwater as their only source of public water supply. Eighty-three (83) communities have a combined groundwater and surface water system. Additionally, 58 communities or 16% have no public water supply systems and thus, on-site, private groundwater systems are used. Together, 275 or 78% of the communities in Massachusetts tap into groundwater systems for drinking water purposes.

Aquifers in the State have been and will continue to be impacted by the legal and illegal disposal of waste. The Massachusetts Department of Environmental Quality Engineering has identified on U.S.G.S. topographic maps approximately 1,600 waste disposal sites that pose a threat to groundwater quality. These sites represent only major sources of contamination, such as landfills, hazardous waste sites, salt storage areas, impoundments and auto junkyards. Additional sources of contamination, such as septic systems, leaking gasoline storage tanks and exfiltrating sewer lines are not included in this survey.

Groundwater pollution is a long-term problem with groundwater quality degradation occurring over many years. When contaminated groundwater is finally discovered it may be impossible and/or very costly to clean up the aquifer. The assumption that is generally made in Massachusetts is that the natural quality of the groundwater is very good. This, and the fact that Massachusetts is considered to be water-rich, result in a lack of concern for monitoring the groundwater quality of public water supplies. The costs of replacing a contaminated water supply, in comparison to establishing a monitoring network, can be excessive. Additionally, the health risks associated with the public's consumption of contaminated water must be included in the cost of not monitoring public water supplies. Thus, the initial capital cost of developing such a network and the long-term annual operating costs represent a fraction of replacement costs. Wilkinson and Edworthy (1981) estimate that an effective water supply monitoring program conducted over a 30 year period would represent only 30% of the cost to replace a contaminated groundwater supply.

In summary, since approximately 38% of the population in Massachusetts uses groundwater as a source of drinking water, suppliers of this water should develop a safety network of monitoring wells to assure the quality of the drinking water. Many waste disposal sites have been identified in Massachusetts as having the potential to affect groundwater quality. It is definitely less costly to the water supplier and to the public to monitor

SOURCE OF WATER SUPPLY for MASSACHUSETTS COMMUNITIES - 1982



Figure 1.

the quality of groundwater supplies rather than locating and developing new public water supplies when existing wells become contaminated.

Edward Selig (1981), legal consultant to the EPA and the firm of Geraghty & Miller, makes a very strong argument in favor of monitoring the quality of public water supplies. He states that,

" Water suppliers are subject to the same rules of product liability as are the other purveyors of goods and services to the consuming public If a company negligently allows its supply to become contaminated, or if it fails to protect its purity through appropriate safeguards, the company may be held liable to pay damages for ensuring injuries." (Emphasis added).

He further clarifies this point by stating that a water supplier solely complying with the monitoring requirements of the Safe Drinking Water Act "will not shield the company from tort liability". His recommendations are that each water supplier protect himself and the supply by:

- o determining the historical and current pattern of waste disposal practices in the recharge area;
- o studying the particular groundwater flow system of the groundwater reserve; and by
- o Instituting technical (monitoring and pumping controls) and political (land use) controls to protect the supply.

Establishing Groundwater Monitoring Objectives

Prior to developing and instituting a groundwater monitoring program, monitoring objectives must be established. This will insure that the information that is collected is sufficient to meet the requirements of the private, local, state, or federal agency requesting the information. There are five types of monitoring that are required by various statutes and regulations in Massachusetts.

- 1) Quality assurance monitoring of potable water supplies. This involves periodic sampling of public supply wells at the wellhead and along the distribution system to determine whether drinking water standards are violated. Installation of groundwater monitoring wells around the supply well and within the area of contribution to the pumping wells is not required but may be advisable as a preventative measure.
- 2) Monitoring to determine long-term trends. This type of monitoring would be undertaken when long-term impacts of changes in land use and pumping patterns need to be quantified.

- 3) Monitoring as a management tool. This may include but is not limited to strategies such as:
 - a. regional evaluation of groundwater resources;
 - b. development of contaminant migration models;
 - c. development of basin-wide water budgets to best define conjunctive use.
- 4) Monitoring for compliance. State and federal regulations require monitoring at sites where groundwater has become contaminated or has the potential for becoming contaminated.
- 5) Unanticipated contaminant release. This could be in the form of:
 - a. Leachate generation from an unregulated or pre-regulated land disposal or storage operation. In this situation, the contaminant source may or may not be identified but the water supply is already affected.
 - b. An accidental spill or pipeline break. What must be ascertained immediately is whether or not there is an aquifer, surface body of water, or other environmentally sensitive area nearby that has the potential for becoming contaminated. This will determine whether or not immediate contaminant isolation is necessary.

There may be other site specific groundwater monitoring objectives not listed here that may need to be defined. Also, a monitoring program may include a combination of objectives.

The following flow chart (Figure 2) provides a very detailed and informative discussion of the factors that should be considered when designing a system for the collection and analysis of groundwater quality data.

As the chart shows, a major emphasis is placed on the definition and review of monitoring objectives. Nacht (1983) explains that the order of activities can change due to the monitoring objectives, site conditions, and political considerations.

Typical groundwater monitoring objectives according to Nacht (1983) are:

- Meeting regulatory requirements;
- Determining site baseline groundwater quality and hydrologic conditions;

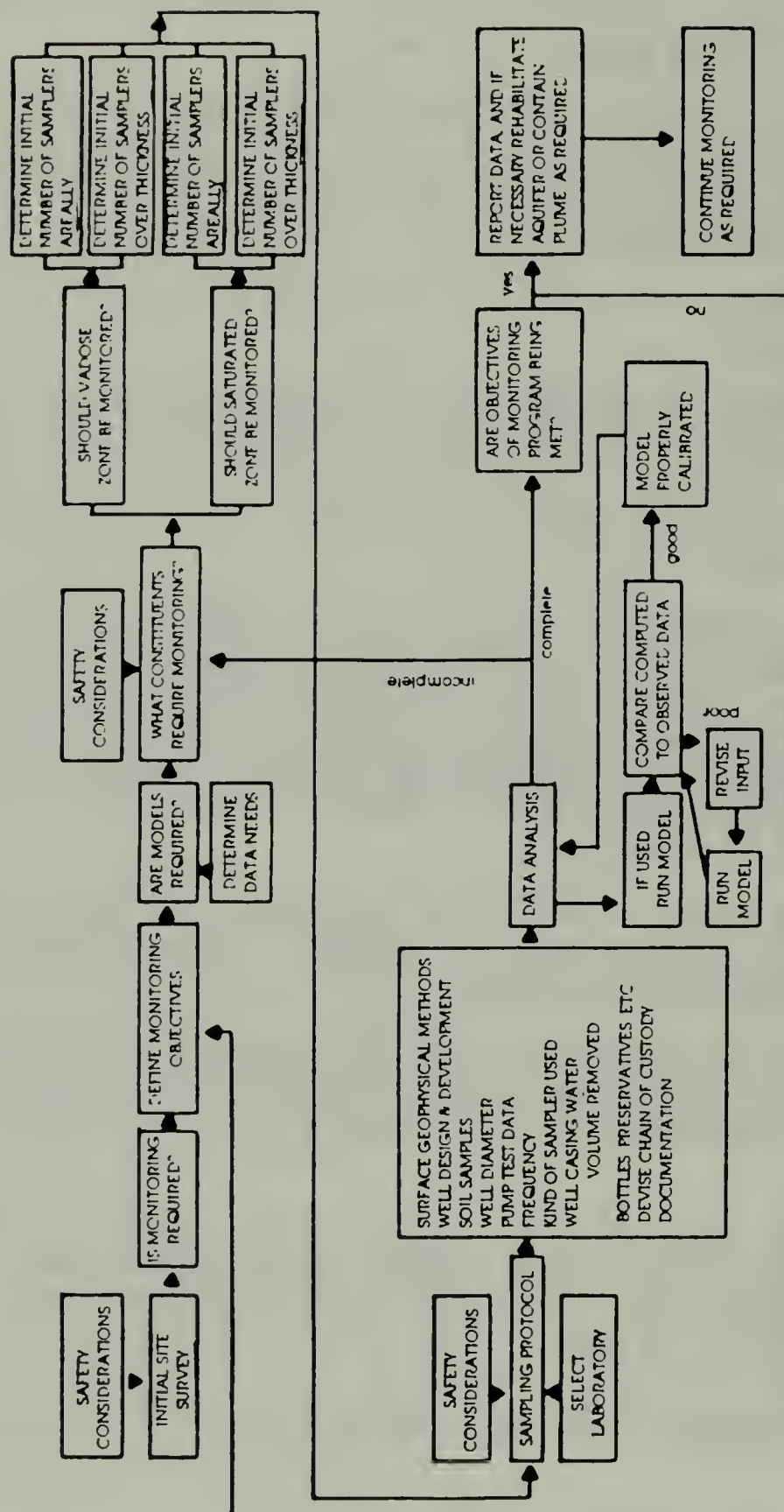


Figure 2. Flow chart for a typical monitoring program. The sequence of events and what is included will vary with the needs and objectives of the monitoring program (after Nacht, 1983).

- Determining why groundwater quality problems are occurring in the area;
- Determining the effect of a facility discharging to the groundwater, a special situation being as an early warning system to determine when pollution has begun or has changed in character or location;
- Determining regional groundwater trends and background groundwater quality.

These objectives are linked to environmental, political or socioeconomic conditions, histories of the problem and hydrogeologic site conditions. Several objectives may be applicable to a given situation. Also, objectives may change over time; thus, they should be periodically reviewed. Monitoring objectives should be clearly defined and documented for the record. This will assist future reviewers of the information with the necessary rationale for the collection of the data. Groundwater monitoring objectives can change during the course of an investigation. A change in objectives should result in a reevaluation of the equipment in use, parameters sampled, and data evaluation methods.

Problems in the Design of Groundwater Monitoring Systems

There are several aspects of groundwater monitoring that are quite different from effluent or surface water monitoring. Generally, they can be summarized as follows:

- 1) Groundwater flow patterns and aquifer boundaries are not visible at the land surface;
- 2) The cost of groundwater monitoring greatly exceeds surface water monitoring;
- 3) Sampling points or wells cannot be moved if it is determined that the wells were improperly located;
- 4) Groundwater is not usually well mixed; as a result, distinct zones of differing water quality both horizontally and vertically are more typical.

The potential for collecting inaccurate groundwater quality data from improperly designed or inadequate monitoring systems is very high. Many factors must be taken into account in the design, installation and sampling of groundwater monitoring systems. The major problems that can result are wasting large sums of money and resources and, more importantly, making wrong decisions on the basis of faulty data.

The following are the most important reasons why groundwater quality monitoring systems can result in inadequate data (Wilkinson and Edworthy, 1981).

- o " The objectives of the monitoring programs are not always properly defined or reviewed. In virtually every case, basic information gained in drilling the monitoring network constitutes a large proportion of the total information available. By making the best use of the opportunity to acquire information at each stage, the amount of effort needed and hence the cost of a monitoring system can be optimized.
- o The monitoring systems are installed before there is sufficient hydrogeological knowledge available on an area. The result is that the network design, choice of sampling method, selection of parameters for analysis and sampling frequency must often be suspect.
- o Insufficient thought is given to the collection, handling, storage, and the accuracy required for the chemical or biological analysis of samples.
- o The data is either not archived at all, so that it is lost to other users, or is archived in such a way that no indication is given as to the circumstances of collection or reliability."
- o Improper well construction and development techniques often result in obtaining data that is suspect. Also, because of the varying degree of chemical resistance of contaminants with different types of piping materials, incorrect selection of the type of material used to construct the finished well can lead to the acquisition of misrepresentative data.
- o Utilizing test pits as monitoring wells wrongly assumes that conditions at the water table are the same throughout the saturated thickness of the aquifer.

These problems must be identified and overcome in order to have a monitoring system that will yield accurate information to make responsible decisions. More detailed information is provided in the following sections.

Variability in Groundwater Quality Data

A properly designed groundwater quality monitoring program presents information on the spatial distribution of groundwater quality parameters. Temporal distribution of the quality of groundwater is determined as samples are collected under natural flow and pumping or recharge conditions. An important step in the design of a groundwater monitoring program is to understand as much as possible about the hydrogeological conditions in the area of concern.

LeGrand (1968) states that "a prerequisite to monitoring is a synthetic hydrogeologic framework or model in which the behavior of the contaminated water is conceived. Unplanned, indiscriminate monitoring of water from wells is expensive, inefficient and fallible".

Large amounts of general information are available from a number of sources to obtain an adequate understanding of the rate of variation. A literature search during the initial planning stages of the investigation will save time and money when the monitoring network is installed.

A very detailed review of spatial-temporal variability in groundwater quality data is provided by Keith et al (1983). Their analysis involved the discussion of variability in regional groundwater quality programs that utilize production wells for sampling. They analyzed data variability sources due to the well-vadose zone-aquifer system relationship (well construction, pumping schedules, geology, hydraulic conditions, and physical-chemical processes), and those due to sample collection and analysis. Controlling the "variability due to well-vadose zone-aquifer system relationships requires monitoring at a frequency sufficient to distinguish the variability due to pumping schedules, hydraulic conditions and physical-chemical processes from the variability of natural background conditions and the impact of land use" (Keith et al, 1983). The major well construction factor of concern in regional monitoring programs is the screen interval. "If water in the aquifer varies vertically or laterally in the vicinity of the well, the quality of water pumped depends on a complex interrelationship of the perforated interval with aquifer heterogeneity, anisotropy and thickness, well discharge, direction of pumping, geology and natural hydraulic head gradients" (Keith et al, 1983). This source of variability can be controlled through pre-monitoring data collection and by choosing sites where construction information is available.

Variability due to pumping rates and schedules can be controlled by strict adherence to a sampling schedule and through resampling to check variability of water quality. Relying upon the well to "stabilize" for field parameters prior to sampling can also result in errors. The sampled parameters may never stabilize or, if they do, it may not mean that all parameters have stabilized.

Sequential sampling in conjunction with drawdown measurements during pump tests provides information on the orientation of the contaminant source (Keely and Wolf, 1983). They state that conventional sampling could possibly lead to serious interpretation errors.

It is generally assumed that groundwater quality remains fairly constant over time and that, as a result, samples may be collected at infrequent and perhaps regular intervals. Research indicates that the opposite is true (Ronen and Kanfi, 1981; Pettyjohn, 1976, 1982). Frequent and rapid changes in NO_3^- , Cl^- , pH, Eh, Ca^{++} , Fe and HCO_3^- have been documented by Ronen and Kanfi (1981). According to Pettyjohn (1976) the "major

cause of cyclic quality fluctuations is intermittent infiltration of water-soluble substances that lie mainly on the land surface or in the groundter-above the water table."

Pettyjohn (1982) describes why cyclic fluctuations in groundwater quality are important. He states that cyclic fluctuations have a significant impact on: groundwater quality monitoring and determination of background quality; transport and fate of organic and inorganic compounds, as well as bacteria and viruses; monitoring well design and installation. Figure 3 shows a schematic diagram of the cyclic movement of chlorides that Pettyjohn found. He proposes that cyclic fluctuations in groundwater quality are a result of storing large volumes of water soluble substances for long periods of time in the unsaturated zone and that the main paths along which contaminants move through the unsaturated zone to the water table consist largely of fractures and macropores such as openings from rotted roots, animal/insect burrows, etc.. His conclusions related to the monitoring of groundwater quality are that it will be necessary to install monitoring wells that can be used to measure vertical head differences and collect samples from discrete sections of the aquifer. Data should be collected frequently, weekly or daily, until a pattern can be established.

Ronen and Kanfi (1981) suggest the use of correlations to determine which hydrogeologic or climatological factors are related to fluctuations in water quality parameters. They provide examples which show the problems associated with cyclic fluctuations when comparing water quality concentrations with regulatory standards. As an example, they tested for nitrates on a monthly basis for 43 wells in the coastal and mountain aquifers in Israel. They found that the concentration trend of a chemical parameter in a well can depend on the sampling scheme. Long-term trends could increase, decrease or remain stable depending on which months were used as comparisons. They state that "as aquifers are not isotropic and both extensive and intensive pollution sources are not uniformly distributed, it is to be expected that groundwater quality will not be uniform." It is suggested that to determine the optimal frequency of sampling for groundwater monitoring you must either study the relationships between fluctuations and causative factors or develop statistical models to enable the calculation of an optimal number of samples to estimate the average concentration of chemical components.

Cyclic fluctuations in groundwater quality can be predicted as follows (Pettyjohn, 1976).

- 1) If the source of contamination has a constant discharge such as a septic system, leaking underground pipe, etc., cyclic fluctuations can still occur due to flushing during recharge events;
- 2) During steady-state conditions (e.g., induced infiltration from a contaminated river) the quality can change due to head differentials and pumping changes;

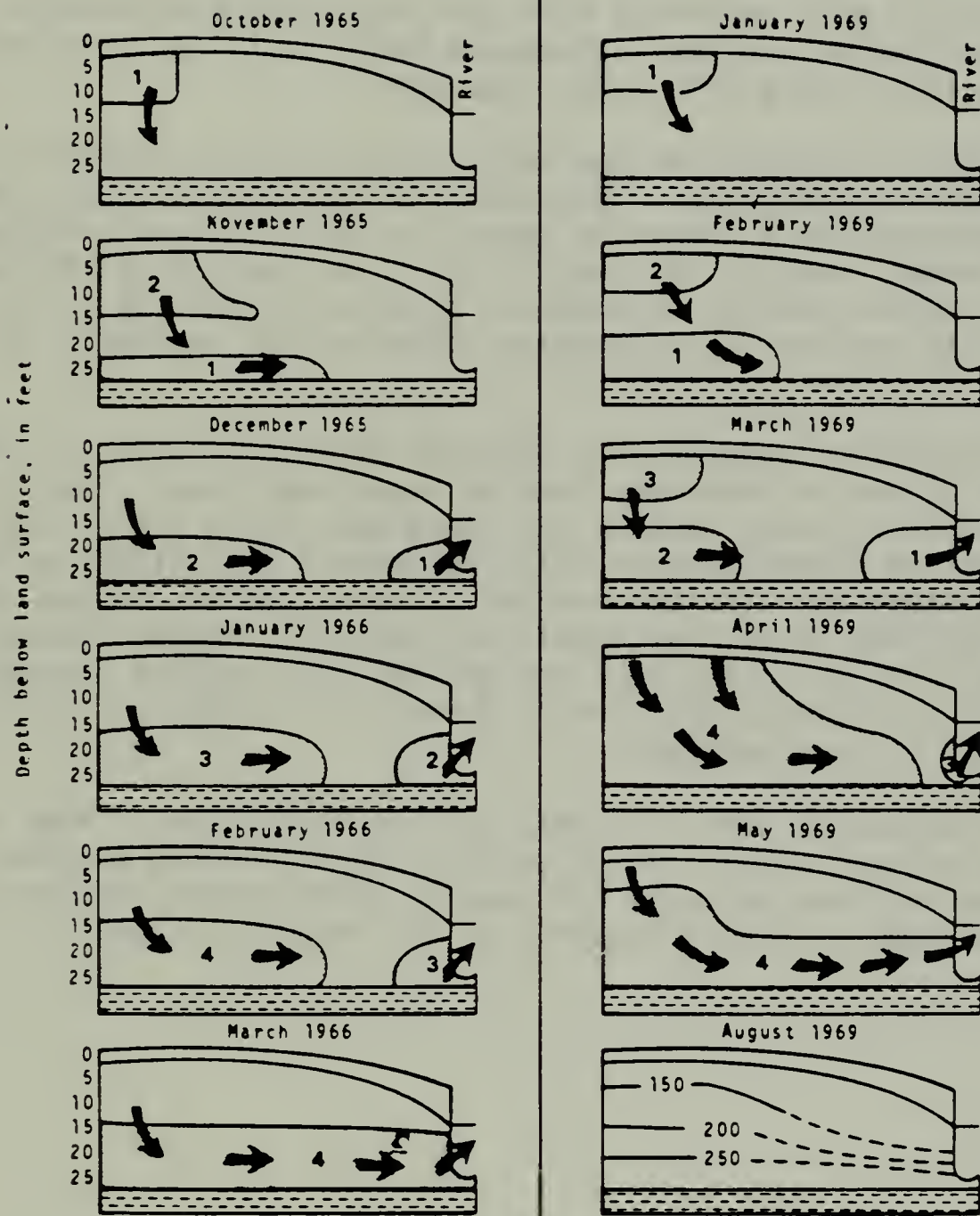


Figure 3. Schematic diagram showing the cyclic movement of masses of contaminated water through the aquifer during selected months in 1965, 1966 and 1969. Stippled areas for 1965-66 represent concentrations in excess of 20,000 mg/l and for 1969 represent concentrations greater than 500 mg/l.

- 3) Most fluctuations occur as a result of water soluble materials in or on the ground affected by direct infiltration;
- 4) In temperate or colder climates the greatest influx should occur during the non-growing season, fall and spring. During the winter the ground surface is usually frozen; thus infiltration is reduced.

Additionally, when reviewing data for particular constituents from a groundwater monitoring program, extraneous data should not be overlooked. A cycle may be developing with other compounds.

Variability in groundwater monitoring data has serious implications in terms of regulatory activities. Regulatory officials are often supplied with data collected for a number of years, by many different people, analyzed by different laboratories and with different analytical methods (Keith et al, 1983). Wading through all of this information and sorting out the unwanted variability is a major obstacle that confronts the regulator.

Barcelona (1983) supports this position by stating that "In the worst case, unknown sources of bias may lead to reporting grossly inaccurate results. Inevitably, such results provide a poor basis for future action, causing the futile expenditure of staff or support with little or no environmental benefit." The only method to recognize and reduce this unwanted variability is for the regulatory agency to develop manuals that would "standardize data collection and analysis and require documentation of the quality of the analytical work" (Keith et al, 1983). This is the primary purpose of this handbook.

The elimination of errors in data and the production of high quality and reliable information is a major goal of any monitoring program. It must be remembered that bad data can lead to questionable conclusions and erroneous enforcement actions required by the regulatory agency.

CHAPTER 2. HYDROGEOLOGICAL INVESTIGATIONS: THE BASIS FOR CONDUCTING A SOUND GROUNDWATER MONITORING PROGRAM

After the pertinent groundwater monitoring objectives have been determined, the next step is to develop an effective site specific monitoring program. This is accomplished by evaluating, in a very detailed fashion, the hydrogeology of the locality. A complete hydrogeological site evaluation should include a description of: (1) the surficial materials and underlying bedrock; (2) the surface and groundwater flow systems; and (3) the climate of the region. Because each of these systems is individually complex, the difficulties in defining the interrelationship between them becomes amplified. Thus it often requires that simplifying assumptions be utilized in the collection and interpretation of field data. Monetary constraints often govern the extent to which these simplifying assumptions are made.

Hydrogeologic investigations are required by state or federal agencies to: (1) determine whether a site will function properly for an intended use; (2) determine the impact of a past, existing or proposed activity on the water resources of a region; or to (3) provide a basis for facility design or site cleanup programs.

The basic elements of a hydrogeologic investigation may include the collection and review of all available data on the study area, field reconnaissance, surface geophysical surveys, test drilling, and analysis of representative samples of surface and groundwater. Depending upon the scope of the intended monitoring program, the detail of investigation into any of these elements may be scaled down or eliminated. Computer-aided, statistical or numerical mathematical modeling may be used when needed.

A literature review and analysis begins by obtaining all available information from a wide variety of sources. Since the objective is to define the site hydrogeology, developing an information base regarding the history of the site is essential. This will greatly facilitate making decisions regarding further investigations and the development of the groundwater monitoring program. The data to be reviewed should include the following types of information sources.

- A. Water well records
- B. Existing geologic reports of the area (published reports; U.S.G.S. Open-file Reports; consultant reports; theses)
- C. Soil and topographic maps
- D. Aerial photos
- E. Previous hydrogeologic studies in area
- F. Groundwater quality data
- G. Surface water quality data
- H. Sanitary or industrial surveys
- I. Characterization of waste
- J. NPDES permits and groundwater or subsurface discharge permits

- K. Expected discharge parameters
- L. Past and present waste hauling and disposal practices
- M. Water supply source and usage amounts
- N. Expected discharge parameters
- O. Past and present waste hauling and disposal practices
- P. Water supply source and usage amounts
- Q. Characterization of site from previous studies-
foundation borings, soil studies, etc.
- R. Location of water usage in area; e.g., irrigation
wells and water supplies
- S. Climatological data
- T. Stream flow data
- U. Geophysical information
- V. Land use studies

On the basis of the review and analysis of the above sources a better understanding will evolve of what additional information is required. This will result in eliminating duplication in the collection of information which means cost savings to the taxpayers of the Commonwealth. Also, a more complete and accurate view of the site hydrogeology is gained.

Tools and Techniques for Defining Site Hydrogeology

Field Reconnaissance

Field observation of the topography, geology, vegetation, surface water/groundwater relationships and pertinent cultural features is an important element to a groundwater monitoring program. It allows for verification of the information gathered in the literature review and provides a basis for selecting further investigative techniques that will be cost effective and meet the monitoring objectives or data needs.

The site topography should be field checked against the most recent U.S.G.S. topographic maps to identify areas that have been changed since the maps were published or that were not mapped properly. The geology of the surficial materials and bedrock, where exposed, should be examined to determine what kinds of materials and structural relationships (i.e., fracture patterns and geologic contacts) exist on the site. The United States Geological Survey has published surficial and bedrock geological maps for many quadrangles in the State (GQ Series) which should be examined.

The type of vegetation can give clues regarding the depth to the water table and soil conditions. The location of stressed or dead vegetation should be identified because it may be indicative of groundwater or surface runoff contamination. Vegetative stress can also be seen on infrared, vertical aerial photographs.

Surface and groundwater characteristics and their interrelationships should be carefully investigated during field reconnaissance. The presence of springs and unmapped swamps and streams, the degree to

which a stream incises the surficial deposits, and the effects that pumping has on nearby surface bodies of water are just some of the information that is pertinent to a hydrogeological study. Engineering activities may also have changed water table levels, which in turn would affect the direction of groundwater flow. Some examples of these engineering activities include pond or lagoon infiltration areas, filled areas, pumping for dewatering, and hydraulic structures such as dams or canals.

The location of cultural features such as power lines and underground pipes should be mapped because their presence can lead to misinterpretation of geophysical information or to a poor choice of drilling methods. Any industries in the vicinity of the aquifer or surface body of water that is being investigated should be catalogued as to type, water requirements and waste disposal practices. This information should be accurately mapped. Pits, ponds, lagoons, and discharge pipes to surface bodies of water (which can be identified by means of a stream walk) should also be located on the site plan. Any past industrial activities should be identified as well as the location of any inactive disposal sites. In this regard local townspeople can sometimes be very helpful. It is not uncommon in a water supply contamination study for there to exist more than one contaminant source. Careful documentation of past and present industrial activity will help to eliminate confusion and identify contaminant sources.

Surface Geophysics

The use of surficial geophysical investigations can yield information about subsurface conditions at a reasonable cost. They cannot replace test drilling but can provide data that can minimize the need for drilling. Information obtained by these methods must be calibrated against testhole information to give accurate results. The decision regarding the choice of techniques to use must be made with the knowledge of the capabilities and limitations of each method. In some situations geophysics is not the most cost effective method of gathering information when the detail and accuracy of the survey needs are considered. Calibration of surface geophysical data with testhole information is necessary because many sets of geophysical data do not have unique interpretations. In other words, differing natural conditions can yield the same geophysical data.

The surficial geophysical methods most often used for determining the hydrogeological setting are:

- Electrical (D-C Resistivity; Electromagnetic);
- Seismic (Reflection; Refraction; Ground Penetrating Radar);
- Other (Gravimetric; Magnetic; Remote Sensing).

The following section is intended to allow the reader to gain an understanding of the capabilities and limitations of these methods. The theory for the interpretation of data will not be presented. Selected references for this information are given where appropriate.

1. Direct Current Resistivity Method

This geophysical technique, developed in the early part of the twentieth century, measures the electrical resistance of earth materials (Zohdy et al, 1974). Measurements are made by placing two pairs of electrodes in the ground along a line, applying a direct current potential to the two electrodes at the ends, and measuring the potential difference between the pair of electrodes in the middle. Three widely used configurations for electrical surveys are the Wenner array, Lee-partitioning array, and the Schlumberger array (Figure 4).

The conduction of electricity is principally electrolytic. This type of conduction is due to the moisture between the grains of soil or in the fractures of rock, which invariably contains some dissolved solids (measured as specific conductance). The resistivity generally depends on the conductivity of the moisture, degree of saturation and the porosity of the medium. Clay minerals and metallic minerals, however, can conduct electricity electronically.

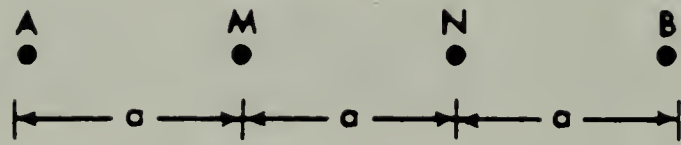
Resistivities of geologic formations vary widely both between and within formations. Measurements that are made are averages of the resistivities of formations and are referred to as apparent resistivities. When the spacing of the electrodes is changed, deductions about the layering of earth materials can be made from the series of apparent resistivities measured.

There are two basic types of D-C resistivity surveys: electrical soundings and horizontal profiles. Electrical soundings are used to determine the variation of resistivity with depth. This is accomplished by increasing the electrode spacing which means that the current will travel progressively deeper through the ground, and will measure apparent resistivity to greater depths. Horizontal profiling can be used to distinguish the variations in lateral resistivities. This type of survey is done by maintaining the electrode spacing while the electrodes are moved in a grid pattern over the land surface. The best results from resistivity surveys are generally obtained using a combination of soundings (to obtain an optimal electrode) and horizontal profiling. Occasionally it is beneficial to make horizontal profiles at two or more different spacings to help distinguish between the effects of shallow structures and deeper ones.

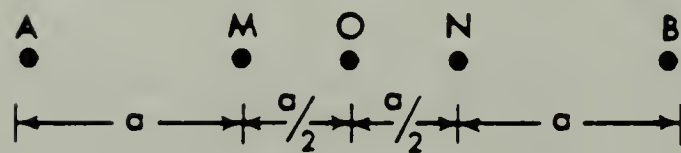
Advantages

The resistivity method is quick and therefore inexpensive. The equipment is highly portable and self-contained. The interpretation is easily accomplished by skilled technicians without a great deal of data manipulation.

The technique works well in certain situations where other methods do not. A clay layer can be detected easily on a sounding but may not appear on a seismic refraction profile. The depth to a fresh



WENNER ELECTRODE ARRAY



LEE-PARTITIONING ELECTRODE ARRAY



SCHLUMBERGER ELECTRODE ARRAY

Figure 4. Wenner, Lee - partitioning, and Schlumberger - electrode arrays. A and B are current electrodes; M, N, and O are potential electrodes; a and $AB/2$ are electrode spacings (after Zohdy et al, 1974).

salt water interface may be determined using the resistivity method as can buried stream channels. Similarly, ground water with contaminants which decrease the resistance can often be delineated from uncontaminated water where there is sufficient contrast in water quality. This technique can be used for spatial and temporal groundwater monitoring by repeating surveys to note changes in apparent resistivity.

Limitations

The interpretation of resistivity data is not often unique to a single situation. This can lead to errors, especially in areas where there are many layers of differing resistivities or where the materials are not relatively homogeneous laterally. The technique may be "short circuited" by the presence of a shallow low resistance layer, pipelines or metal fences. Overhead power lines can induce current in the ground and lead to errors. Also, there may be a "depth of penetration" limit due to the area required to spread the array. Errors can also occur where the topography is steep or the land has been used for different purposes. Interpretive errors may occur where layers of varying resistivities do not coincide with geologic layering or where the geoelectric properties are the same for differing geologic layers. When the water table is overlain or underlain by layers of differing resistivity, it is often difficult to detect it on an electrical sounding (Zohdy et al, 1974), although it is frequently attempted.

2. Electromagnetic Terrain Conductivity Method

The electromagnetic (inductive) technique is used to determine the conductivity of earth materials. Conductivity, the inverse of resistance, is expressed in units of mhos (Siemens) per meter or, for convenience, in millimhos per meter.

The principle of operation is the induction of an alternating current magnetic field through a transmitter coil and the sensing of this induced magnetic field, together with the primary magnetic field, by a receiver coil. The induced or secondary magnetic field is a function of the spacing between coils, the current frequency and the ground conductivity. The measurement of conductivity at varying depths is possible because the depth of penetration is dependent on the current frequency.

The applications of electromagnetic techniques are similar to those of D-C resistivity surveys and include:

- delineating gravel deposits,
- mapping fresh-saline groundwater boundaries,
- detecting cavities in carbonate rocks,
- mapping pollution plumes in groundwater and,
- general geologic mapping (soil types, fault/fracture zones, bedrock topography and extent of permafrost).

Advantages

The principal advantage is the speed and accuracy with which lateral changes in conductivity (resistivity) can be measured. This is because there are no electrodes to be driven into the ground. There are no earth conduction problems because the currents are magnetically induced. The layered earth calculations are simple. A continuous record of data can be made with simple modifications to the equipment. The technique requires less space between the coils than the D-C resistivity spread for the same depth of penetration. Depth penetration capabilities are approximately 3 feet to 200 feet and this technique can be used over asphalt and concrete.

Limitations

The vertical sounding capability is restricted to measuring the conductance at only a few predetermined depths (10, 20 and 40 meters). There may be instrumentation in the future that will allow a wider variety of depths; however, it will be more complex. There is also a limit to the range of conductivities that can be measured. Generally, the detection is within 1-1000 millimhos per meter. As is true for other geophysical techniques the information obtained from the data reduction must be calibrated with testhole information.

3. Seismic Refraction

Seismic methods use artificially created seismic waves generated on the surface to determine what the sub-surface looks like. By measuring the arrival times of seismic waves at various distances from the energy source, depth to bedrock, shape of the bedrock surface, depth to the water table and, in some cases, the general lithology, can be evaluated. The energy source can be a small explosive charge or by weight drop when lower energies are acceptable or the use of explosives is limited. The detection of the seismic energy waves is accomplished using geophones. Geophones are devices sensitive to ground motion and create an electric impulse when the elastic waves arrive.

There are two commonly used seismic methods: reflection and refraction. Seismic reflection, used to determine structural and formational boundaries at great depth, is seldom justified in relation to the objectives and budgets of groundwater studies, and is used almost exclusively by the petroleum industry. Seismic refraction is used to determine the thickness of unconsolidated material overlying bedrock, which is one of the principal parameters to be identified in any hydrogeological study.

The seismic refraction method produces a profile of the various layers of earth materials if, (1) each layer has a uniform seismic velocity, and (2) the velocity of each layer increases with depth. The refraction survey is performed by measuring the length of time for the first arrival of the

elastic wave from the energy-source at various distances from the "shot". The use of a multi-channel recorder typically allows 12 to 24 geophones to be used for each "shot" resulting in a great savings in time; however, the same results can be obtained with less complex equipment. A typical refraction line is 200 to 800 feet in length with "shot" points at either end and occasionally in the middle to obtain a better data set. In a similar manner to D-C resistivity surveys where correlation could be made to geologic materials based on their resistivities, seismic refraction data can be interpreted to give the thickness of geologic materials.

Advantages

Seismic refraction is useful in determining depth to water table, saturated thickness, thickness of till, depth to bedrock, and slope of the bedrock surface.

Limitations

The limitations of the refraction survey are mainly: the inability to distinguish thin seismic layers when bounded by relatively thick layers; geologic layers that have similar seismic velocities; and a condition called velocity inversion. Occasionally, small structures are missed: for example, a small buried valley which is nearly perpendicular to the refraction line. This technique must be supported with information from well logs so that the validity of interpretations is assured. A misinterpretation of the type of geologic unit can result from situations such as a very compact till being confused for fractured bedrock, or by saturated overburden with layers of clay, sands or gravel which are indistinguishable because they have similar seismic velocities. Although the water table is one of the surfaces that may be calculated with this method it is actually the top of the capillary fringe which is estimated.

The amount of space required to obtain the necessary depth of penetration is dependent upon the seismic velocities of the layers and therefore the length of the geophone spread can be quite long. A seismic survey line typically needs to be approximately three times as long as the depth of the desired interface. In some areas background noise, from highways and airplanes for instance, can limit the use of refraction surveys.

4. Ground Penetrating Radar

Ground-penetrating radar is a seismic reflection technique using short-wave-length radio waves for the energy source. The technique is relatively new and has not been used extensively. However, it has some attractive capabilities. The equipment used consists of a small sled which holds the energy source and receiver. The radar waves penetrate the ground and are reflected back to the receiver with varying strengths, depending upon the quality of the geologic materials or objects detected in the ground.

Advantages

A profile of the subsurface is made in an easy and continuous manner by the chart recorder. The location and depth to geologic layers can be readily interpreted by a technician and because objects such as pipes and drums are good reflectors they are easily identified. Areas where the water table is close to the land surface are easy to identify and contamination plumes can be easily mapped. This technique may also be used over paved areas. A survey line can be made approximately as fast as one can walk.

Limitations

The depth of penetration is limited to approximately 15 feet. Access in vegetated or wooded areas for the power generator and the chart may be a problem. In addition, a shallow depth, high strength reflector such as the water table may mask underlying materials.

5. Gravimetry

Gravity can be used to delineate the area and depth of unconsolidated basin fill or buried stream-channel aquifers. The technique utilizes the fact that the gravitational pull of the earth is dependent upon its mass and the distance to the center of the earth. Because the earth is not homogeneous, there are differences in the acceleration of gravity observed at the surface. These gravitational differences are associated with geologic structures within the outer portion of the crust. A sensitive instrument called a gravimeter is used to measure these differences. The application of gravimetry to hydrogeology can provide a method of determining areas of maximum aquifer thickness, tracing buried channels and locating shallow bedrock areas.

Advantages

This method requires only one person and data can be gathered relatively quickly. A map showing the contours of equal gravity generally mimics the topography of the underlying bedrock surface.

Limitations

The use of the gravity method requires the data to be gathered accurately. Data reduction requires corrections for latitude, tide, terrain and instrument drift. Additionally, the elevation of the reading stations needs to be known very accurately.

6. Magnetic Surveys

Magnetic surveys, like gravity surveys, can be used to map the areal extent and depth of unconsolidated deposits. The earth's magnetic field is distorted by magnetic materials in the earth's crust. These distortions

are the result of two types of magnetization. The strongest type is the induced magnetism from the earth's magnetic field. A minor portion is caused by the strength and direction of the earth's magnetic field at the time that minerals containing iron and nickel crystallize from a melt or sedimentary deposits containing these minerals lithify. Magnetic surveys measure the latter or anomalous magnetism.

Advantages

Surveys can be done with relatively simple surface instruments that can be carried by one person or they can be made over large areas using an airborne unit. Aeromagnetic maps for Massachusetts at a scale of 1:24,000 have been completed and published by the United States Geological Survey. These maps show contour lines of the total intensity of the earth's magnetic field. This information can be used to infer contacts between rock types of differing magnetic intensities. When very accurate surveys are performed other relationships may appear, such as low magnetic trends where intense fracturing has allowed the magnetite in the bedrock to weather to non-magnetic minerals.

Summary of Geophysical Methods (After Benson et al., 1982)

This section presents a summary of, as well as additional information on, the geophysical methods discussed in this document. The following tables highlight features of each method and are intended as general guidelines to provide the reader with a capsule summary of the capabilities and limitations of the methods, including factors which may affect their measurements. These tables are based on extensive field experience, and they present data which will be applicable in most cases. However, the reader should use them as guidelines, recognizing that exceptions may occur because of the wide range of site conditions and project objectives.

- Table 1 - Applications of geophysical methods to hazardous waste sites.
- Table 2 - Summarizes the primary technical characteristics of the six methods, including: mode of measurement, depth of penetration, relative resolution, and data format.
- Table 3 - Outlines primary (more suitable or more commonly used) and secondary (less commonly used or less effective) applications of each method.
- Table 4 - Lists sources of noise which may affect the performance and utilization of each method.

No single method, whether traditional direct sampling or one of the contemporary geophysical techniques, will solve all site investigation problems. All the methods discussed are founded on sound scientific principles and can be extremely effective in the field; but any of them may

APPLICATION	ELECTROMAGNETICS					RESISTIVITY	SEISMIC	METAL DETECTOR	MAGNETOMETER
	RADAR								
Mapping of Geohydrologic Features	1	1	1	1	1	-	-	-	-
Mapping of Conductive Leachates and Contaminant Plumes (ex. Landfills, Acids, Bases)	2	1	1	1	-	-	-	-	-
Locations and Boundary Definition of Buried Trenches with Metal	1	1	2	2	2	2	2	2	2
Location and Boundary Definition of Buried Trenches without Metal	1	1	2	2	2	-	-	-	-
Location and Definition of Buried Metallic Objects (ex. Drums, Ordnance)	2	2	-	-	-	1	1	1	1

1. Primary method - Indicates the most effective method
2. Secondary Method - Indicates an alternate approach

Table 1. Applications of geophysical methods to hazardous waste sites (after Benson et al, 1982).

METHOD	RESPONDS TO CHANGE IN	MODE OF MEASUREMENT	DEPTH OF PENETRATION	RESOLUTION	RAW DATA FORMAT
1. Ground Penetrating Radar (GPR)	Complex Dielectric Constant of soil, rock, pore fluids, and man-made objects	Continuous Profile .4 Km/hr. detail - 8 Km/hr. reconnaissance (Ground contact not necessary)	One to ten meters typical - highly site specific. Limited by fluids and soils with high electrical conductivity and by fine grain materials.	Greatest of all six geophysical methods	Picture-like graphic display. Analog tape Digital tape
2. Electromagnetics (EM)	Bulk electric conductivity of soil, rock and pore fluids (Pore fluids tend to dominate)	Continuous Profiles to .5 to 15 meters depth. Station measurements to 15 to 60 meters depth. Some sounding capability (Ground contact not necessary)	Depth controlled by system coil spacing .5 to 60 meters typical	Excellent lateral resolution. Vertical resolution of 2 layers. Thin layers may not be detected.	Numerical values of conductivity from station measurements. Stripchart and/or magnetic recorded data yields continuous profiling.
3. Resistivity Sounding (RES)	Bulk Electrical resistivity of soil, rock and pore fluids (Pore fluids tend to dominate)	Station Measurements for profiling or sounding (Must have ground contact)	Depth controlled by electrode spacing. Limited by space available for array. Instrument power and sensitivity become important at greater depth.	Good vertical resolution of 3 to 4 layers. Thin layers may not be detected.	Numeric values of voltage current and dimensions of array. Can plot profile or sounding curves from raw data.
4. Seismic Refraction	Seismic velocity of soil or rock which is related to density and elastic properties.	Station Measurements (Must have ground contact)	Depth limited by array length and energy source.	Good vertical resolution of 3 to 4 layers. Seismic velocity must increase with depth - thin layers may not be detected.	Numeric values of time and distance. Can plot T/D graph from raw data.
5. Metal Detector (MD)	Electrical conductivity of ferrous and non-ferrous metals	Continuous (Ground contact not necessary)	Single 55 gal. drum up to 2 3 meters Massive piles 55 gal. drums up to 6 meters	Very good ability to locate targets	Relative response from audio/visual indicators (may record data)
6. Magnetometer (MAG)	Magnetic susceptibility of ferrous metals	Continuous Total Field or gradient measurements. Many instruments are limited to station measurements. (Ground contact not necessary)	Single 55 gal. drum up to 2 6 meters Massive piles 55 gal. drums up to 20 meters	Good ability to locate targets	Non-quantitative response from audio/visual indicators. Quantitative instrument provides meter or digital display (may record data)

1. Depth is also related to equipment capability.

2. Depth is very dependent upon instrument used.

Table 2. Characteristics of geophysical methods (after Benson et al, 1982).

Application	Radar	EM	Res	Seismic	MD	MAG
NATURAL CONDITIONS - Layer thickness and depth of soil and rock Mapping lateral anomaly locations Determining vertical anomaly depths Very high resolution of lateral or vertical anomalous conditions Depth to Water table	1 1 1 1 2	2 1 2 1 2	1 1 1 2 1	1 1 1 2 1	NA NA NA NA NA	NA ** NA ** NA NA NA
SUB-SURFACE CONTAMINATION LEACHATES/PLUMES - Existence of contaminant (Reconnaissance Surveys) Mapping contaminant boundaries Determining Vertical extent of contaminant Quantify magnitude of contaminants Determine flow direction Flow rate using 2 measurements at different times Detection of organics floating on water table Detection & Mapping of contaminants within unsaturated zone	2 * 2 * 2 * NA 2 * NA 2 * 2	1 1 2 1 1 1 2 * 1	1 1 1 1 1 1 2 * 1	NA NA NA NA NA NA NA NA	NA NA NA NA NA NA NA NA	NA NA NA NA NA NA NA NA
LOCATION AND BOUNDARIES OF BURIED WASTES - Bulk Wastes Non-Metallic containers Metallic Containers - Ferrous - Non-ferrous Depth of burial	1 1 2 2 2	1 1 1 1 2	1 1 NA NA 1	2 2 NA NA 2	NA NA 1 1 2 *	NA NA 1 NA 2 *
UTILITIES - Location of pipes, cables, tanks Identification of permeable pathways associated with loose fill in utility trenches Abandoned Well Casings	1 1 NA	1 1 NA	NA NA NA	2 2 NA	1 1 1	1 1 1
SAFETY - Pre-drilling site clearance to avoid drums, breaching trenches, etc.	1	1	2	NA	1	1

1 - Denotes primary use
 2 - Denotes possible applications, secondary use; however, in some special cases 2 may be the only effective approach due to circumstances.
 NA - Not applicable
 * - Limited applications
 ** - Not applicable in the context used in this document.

Table 3. Typical applications of geophysical methods
 (after Benson et al, 1982).

Table 4. Susceptibility of geophysical methods to noise (after Benson et al, 1982).

This table shows the susceptibility of the geophysical methods to various forms of "noise" which may influence field operation, resulting data and subsequent interpretation.

SOURCE OF NOISE	RADAR	EM	RESISTIVITY	SEISMIC	MD	MAG
Buried Pipes	will detect, but may affect data	1 only if close to pipe	1 only if survey is parallel and close by	2 only if survey is directly over	1 any metal pipes	1 steel pipes only
Metal Fences	NA	1 only if close to fence	2 only if survey line is parallel & close to fence	NA	2 only if nearby	1 steel fences only
Overhead Wires (powerlines)	2 only if unshielded antennas are used	1	NA	NA	NA	2 some mag respond
Ground Vibrations	NA	NA	NA	1	NA	NA
Airborne Electro-magnetic Noise	NA	2	2	NA	2	1 to 2 (Earth's Field Changed)
Ground Currents and Voltage	NA	NA	2	NA	NA	NA
Trees	2 only if unshielded antennas are used	NA	NA	2 (Wind noise)	NA	NA
Metal from Buildings, Vehicles, etc.	2 only if nearby & unshielded antennas are used	2 only if nearby	2 only if nearby	NA	2 only if nearby	2 only if nearby
Small Metallic Debris on Surface or Near Surface (nails, wire coathangers)	2	NA	NA	NA	1	1 ferrous metal only
Large Metallic Debris on Surface or Near Surface (Drums, Drum Covers, etc.)	2	2	2	NA	1	1 ferrous metal only
Susceptible to noise from ground contact/ Electrode problems	2	NA	1	2	NA	NA

1 - Very Susceptible
2 - Minor Problem
NA - Not Applicable

fail, when improperly applied or when applied to the wrong objective. The methods and approach discussed in this document have been successfully applied to a number of site investigation problems as outlined in Table 3. A large number of sites have been evaluated throughout the United States with a diverse set of both hazardous waste and geohydrologic conditions. In addition, the approach has been used repeatedly in evaluation of new disposal sites, and to evaluate conditions after clean-up or remedial action has occurred. By selecting the most suitable methods, combining methods, and utilizing the synergistic benefits of an integrated systems approach, high levels of accuracy and cost-effectiveness can be achieved in subsurface investigations of hazardous waste sites.

Remote Sensing

Remote sensing techniques include photographic techniques and the sensing of emitted or reflected radiation of varying lengths. The most commonly used techniques include:

- Aerial Photographs: Black and White, Color, Infrared (false color), and Multispectral Photographs
- Side Looking Airborne Radar (SLAR)
- LANDSAT Images

1. Aerial Photography

Aerial photography is used to make topographic maps, determine areas of stressed vegetation which may be the result of contaminated groundwater or/and surface water, and provide a mechanism for updating, or true monitoring, by taking photographs repeated at appropriate time intervals. Black and white photographs are typically available in stereo pairs at a relatively low cost from a variety of sources through the Massachusetts Department of Public Works, Geodetics Division. Aerial photographs for Massachusetts have been summarized by the New England River Basins Commission, 1979. Site specific color photographs may indicate areas of advanced vegetative stress while infrared photographs may be able to distinguish less advanced levels of stress. Another photographic method which can be used is multispectral photography. A multi-lens camera is used with various filters to emphasize the difference between stressed and normal vegetation. The images can be projected through colored filters and overlapped to further enhance the effect.

2. Side Looking Airborne Radar

Side Looking Airborne Radar (SLAR) is a sensing system in which an antenna on the side of an aircraft transmits pulses of microwaves to the land surface and receives a signal the strength of which corresponds to the

surficial material. As the aircraft moves along a flight line, a continuous oblique image of the ground surface is obtained. The wavelength selected for the sensing system, the transmission path and the characteristics of the earth's surface interact to affect the amount of energy returned to the sensor, and thus, the tonal brightness of the image.

Although radar data is well suited for geologic mapping and resource surveys for mineral or petroleum exploration, it is also useful for providing information on terrain relief and drainage patterns because it is insensitive to vegetation. Radar images are particularly useful in areas which are persistently cloud-covered. These images have proven to be especially good for bedrock fracture trace analyses.

3. Landsat

Landsat images are false color infrared spectral images relayed from an earth orbiting satellite. The coverage of these images is very wide and these photographs are most often used for regional analyses of geologic features. Potential mineral and groundwater indicators such as faults, fractures, and other linear features are evident on individual Landsat frames or groups of frames called mosaics.

CHAPTER 3. CONSTRUCTION OF MONITORING WELLS

Information obtained from any of the surface geophysical or remote sensing methods previously described must be calibrated to the site geohydrology. This is accomplished by the installation of monitoring wells at selected locations and depths to identify the local geology and to sample water in the saturated zone and in the unsaturated zone (when applicable). Prior knowledge of the physical properties of the types of contaminants that are present (i.e., density, viscosity, miscibility) and how they generally react with different types of soils will aid in deciding where in the soil profile soil samples should be taken and whether or not sampling of water in the unsaturated zone or at various depths in the saturated zone is appropriate. This is particularly true when the contaminants are heavy metals, which have an affinity for adsorbing to clay mineral particles, or to volatile organics which may either float on the water table, mix, or sink to the bottom of the aquifer. Properties of common contaminants and sampling methods will be discussed in subsequent sections.

General Information

In order to be cost-effective, drilling program requirements need to be carefully defined to choose the best method, contractor and equipment. Several variables, such as geologic materials, contaminant parameters of interest, and budget, greatly influence the decision making process. The more common types of drilling methods for geologic sampling, monitoring well and observation well installations are: cable tool, hydraulic rotary, auger (solid stem, hollow stem, hand), jet drilling, wash and drive, and driven points. Less common types include the air-rotary and air-rotary percussion methods.

These types of drilling methods need to be compared for their relative advantages and limitations with respect to the parameters of interest for the project. A list of the common factors used to evaluate drilling methods includes the following: availability; mobility for access; depth range; casing requirements; water, soil and rock sampling abilities; speed; drilling fluids introduced; hole size; cost.

Table 5 indicates that some types of drilling are better suited for the needs of some projects but may not be good for others. For example, if the requirements were to sample both soil and water while drilling a test boring, the use of a hydraulic rotary drilling rig would be inappropriate. This technique is very good for soil sampling but poor for obtaining representative water samples.

Table 5. Comparison of drilling methods.

	Wash & Drive	Drive Points	Auger (Solid)	Cable Tool	Hydraulic	Rotary Air	Special Reverse
=====	=====	=====	=====	=====	=====	=====	=====
Availability	Good	Good	Good	Good	Good	Low	Low
Mobility/Access	Very Good	Very Good	Good	Good	Good	Poor	Low
Max. Depth Range	200 ft.	100-150 ft.	100-150 ft.	500-1000 ft.	1000+ ft.	1000+ ft.	1000+ ft.
Casing Requirements	Yes	N/A	No/Integral	Yes	No	Yes	No
Sampling: Water	Good	Good/Poor	Poor/Good(2)	Good	Poor	Good	Good
Soil	Good	N/A	Poor/Good	Poor	Very Good	Poor	Good
Rock	N/A	N/A	N/A/Possible	Poor	Very Good	Poor	Poor
Speed	Slow to Moderate	Fast	Fast	Slow	Moderate	Very Fast	Moderate
Drilling Fluids: Soil	Water	None/Water	None	Small Amounts	Mud	Mud	Mud
Rock	N/A	N/A	N/A/Water	of Water	Water	Air or Foam	Water
Hole Size(1)	2-6 in.	2 inches	6 in./8 in.(3)	4+ inches	2 3/8-6 in.	6+ inches	6+ in.
Relative Cost	Low	Low	Moderate	Moderate	Moderately High	High	Very High

(1) Hole sizes typical for monitoring wells

(2) Using special equipment for Hollow Stem Augers

(3) Hollow Stem Augers are typically 8" outside diameter with 2½-3½ in. inside diameter, larger sizes now available.

Drilling services are generally available from two different types of contractors: water well drillers and test boring contractors. Water well drillers are commonly more experienced in the installation of wells and developing the wells to assure that they function properly. However, some well drillers are not as familiar with soil and rock sampling techniques that are commonly used in the geotechnical engineering field. Here many test boring contractors have an advantage, both in skills and equipment. As monitoring groundwater becomes more common, both types of drilling contractors will gain expertise where deficiencies may now exist.

The mobility which one type of rig has over another, under specific site conditions, depends to a great extent on the type of mounting. Some of the more common types of mounts are: truck, trailer, tracked crawler, skids and all terrain vehicles. Drilling contractors often have more than one type of drilling mount available to reduce access problems for difficult sites.

Depth ranges presented in Table 5 are generalized. The geologic materials, as well as the size and power of the drill rig, affect the actual depth obtainable. For example, a hydraulic rotary rig is typically limited by its ability to lift the drilling tools out of the ground.

Casing may be necessary to prevent a borehole from collapsing. However, this may interfere with obtaining a borehole geophysical survey. The limitations are described in the section reviewing borehole geophysical techniques.

Sampling for water while advancing the hole is often desirable to profile groundwater quality against increasing depth. In order to define the stratigraphy of the aquifer, soil sampling at five foot intervals is also strongly recommended. The type of drilling equipment should be evaluated not only for ease of obtaining these samples but for the method of sampling and for materials the sample will come into contact with as the sample is withdrawn from the ground. Soil and rock sampling technology is discussed later, as well as more specific information regarding water sampling techniques.

The speed of drilling is an important consideration to reduce the overall costs. However, because soil and water sampling at five foot intervals is generally required, by necessity drilling time greatly increases. For example: a geologist is often assigned to provide geologic interpretation and quality assurance during drilling and well installations. Many contracts specify the units for payment, such as an hourly rate or a per footage rate of payment. For small amounts of drilling the footage rate may not be agreeable to the contractor and an hourly rate may be required. Contracts for larger jobs may specify a footage rate for the actual drilling and an hourly rate for the installation of wells, development and sampling. This arrangement is often advantageous in obtaining the highest quality of work while providing an incentive for completing the work quickly.

The introduction of drilling fluids (other than water) may affect the quality of subsequent water sampling. Drilling fluid may alter the formation water, bentonite mud may adsorb metal ions, and biodegradable muds may change the biological characteristics of groundwater samples. For these reasons the "dry" methods of drilling are often preferred where feasible. Other considerations may include water availability. For example, jetting requires large amounts of water and would not be a good choice if water needed to be hauled or piped for long distances.

Hole size may be important for several reasons. The hole diameter should be 2 inches larger than the well casing diameter to allow proper placement of grout or bentonite seals (Scalf et al, 1981). Large diameter wells have excessive storage which would require large amounts of water to be removed prior to sampling. To further complicate matters, longer periods of time are required for groundwater levels to stabilize in large diameter wells, which could cause errors in data interpretation.

In summary, the cost for drilling is related to the speed but also involves the sophistication of the equipment involved and the manpower required to run and support the drilling efforts.

Drilling Methods

The following information on the construction of monitoring wells and advantages and disadvantages of each has been taken from A Manual of Groundwater Sampling Procedures (Scalf et al, 1981) and is used with permission from the National Water Well Association.

Selection of the drilling method best suited for a particular job is based on the following factors in order of importance:

- (1) Hydrogeologic Environment
 - (a) Type(s) of formation(s)
 - (b) Depth of drilling
 - (c) Depth of desired screen setting below water table
- (2) Types of pollutants expected
- (3) Location of drilling site - dry land, or inside a lagoon
- (4) Design of monitoring well desired
- (5) Availability of drilling equipment

The principles of operation, advantages and disadvantages of the more common types of drilling techniques suitable for constructing groundwater monitoring wells are discussed as follows.

1. Solid-Stem Continuous-Flight Auger

Principles of Operation: Drilling is accomplished by rotating the solid stem, continuous-flight augers into the soils. As the augers are

"screwed" into the soils, the cuttings are brought to the surface on the rotating flights (Figure 5). Auger bits are essentially of two types: fish tail or drag bits for use in unconsolidated materials, and claw or finger bits for use in more compacted, lithified or cemented soils. Once the desired depth is reached, the augers are allowed to rotate to clean out the borehole. The augers are then removed from the borehole and well screen and casing installed. This method is best applied when installing monitor wells in shallow unconsolidated formations.

Advantages:

- (1) The auger drilling rigs are generally mobile, fast and inexpensive to operate in unconsolidated formations.
- (2) Small amounts of drilling fluid are used; consequently, contamination problems are minimized.

Disadvantages:

- (1) Cannot be used in hard rock.
- (2) Depth limitation varies with equipment and type of soils but approximately 150 feet is maximum.
- (3) Once the augers have been withdrawn, the degree to which the borehole will remain open is dependent upon the degree of soil consolidation and saturation. Most boreholes will collapse below the water table.
- (4) Formation samples may not be completely accurate.
- (5) Depth to the water table may be difficult to determine accurately in deep borings.

2. Hollow-Stem Continuous-Flight Auger

Principles of Operation: This method differs from the solid stem augers in that the stem is hollow. Upon reaching the desired depth, a smaller diameter casing and screen can be set inside the hollow stem. The augers are then pulled out as the casing is held in place.

Advantages:

- (1) The auger drilling rigs are generally mobile, fast, and inexpensive to operate in unconsolidated formations.

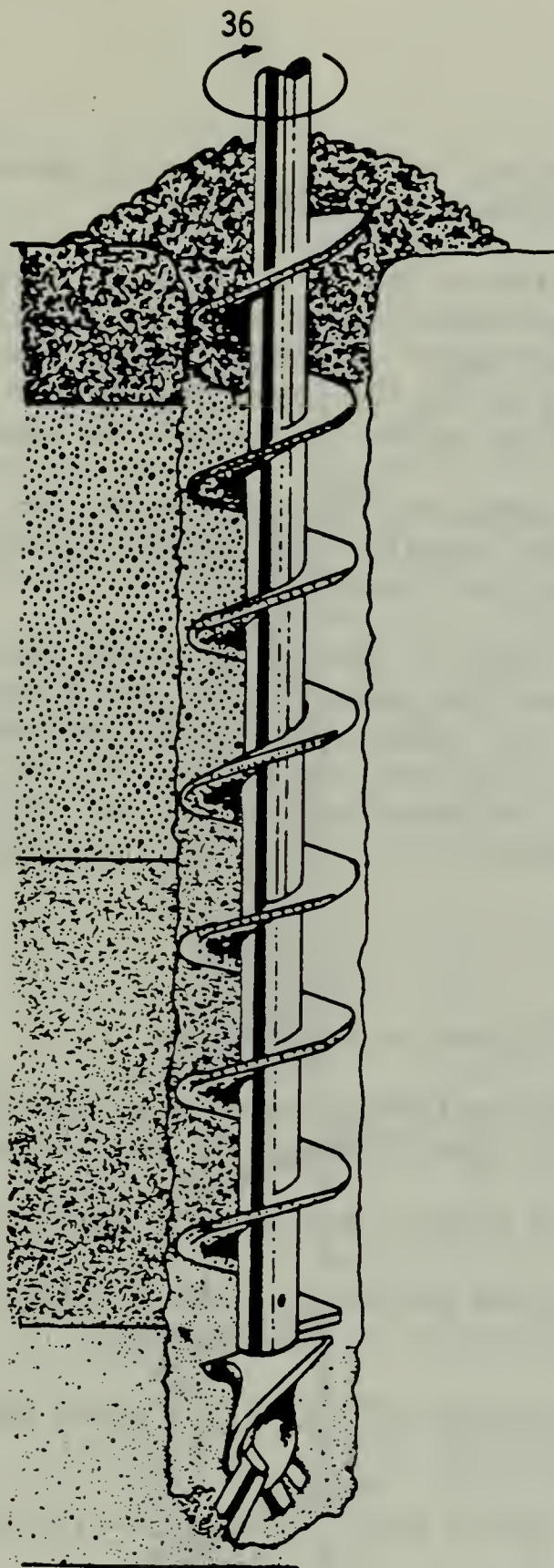


Figure 5. Continuous flight auger drilling. The continuous-flight auger bores into the soil and rotates the cuttings upward along the flights. The uppermost cuttings are discharged at the surface to make room for the space of the auger as it penetrates additional soils (after Scalf et al, 1981).

- (2) Small amounts of fluid are used; therefore, contamination problems are minimized.
- (3) The problem of the hole caving in saturated, unconsolidated material, as when the solid-stem, continuous-flight auger is pulled out of the hole, is overcome by placing the casing and screen down inside the hollow stem before the augers are removed.
- (4) Natural gamma-ray logging can be done inside the hollow-stem which permits defining the nature and thickness of the formations penetrated.
- (5) A grout seal can be placed around the permanent casing by attaching a cement basket above the screen before setting the assembly inside the hollow-stem. Grout is placed in the annulus between the casing and hollow-stem as the augers are pulled out. Grout is continuously injected or placed until all augers are removed.

Disadvantages:

- (1) Cannot be used in hard rock.
- (2) Depth limitation varies with equipment and type of soils but approximately 150 feet is practical.
- (3) Formation samples may not be completely accurate.
- (4) Depth to the water table may be difficult to determine accurately in deep borings.
- (5) Most boreholes will collapse below the water table.

3. Keck Screened, Hollow Stem, Continuous-Flight Auger

Principles of Operation: This method operates the same as the hollow stem augers except that the lead section incorporates a well screen (Figure 6).

Advantages:

- (1) The auger drilling rigs are generally mobile, fast and inexpensive to operate in unconsolidated formations.
- (2) Little fluid is used; therefore, contamination problems are minimized.

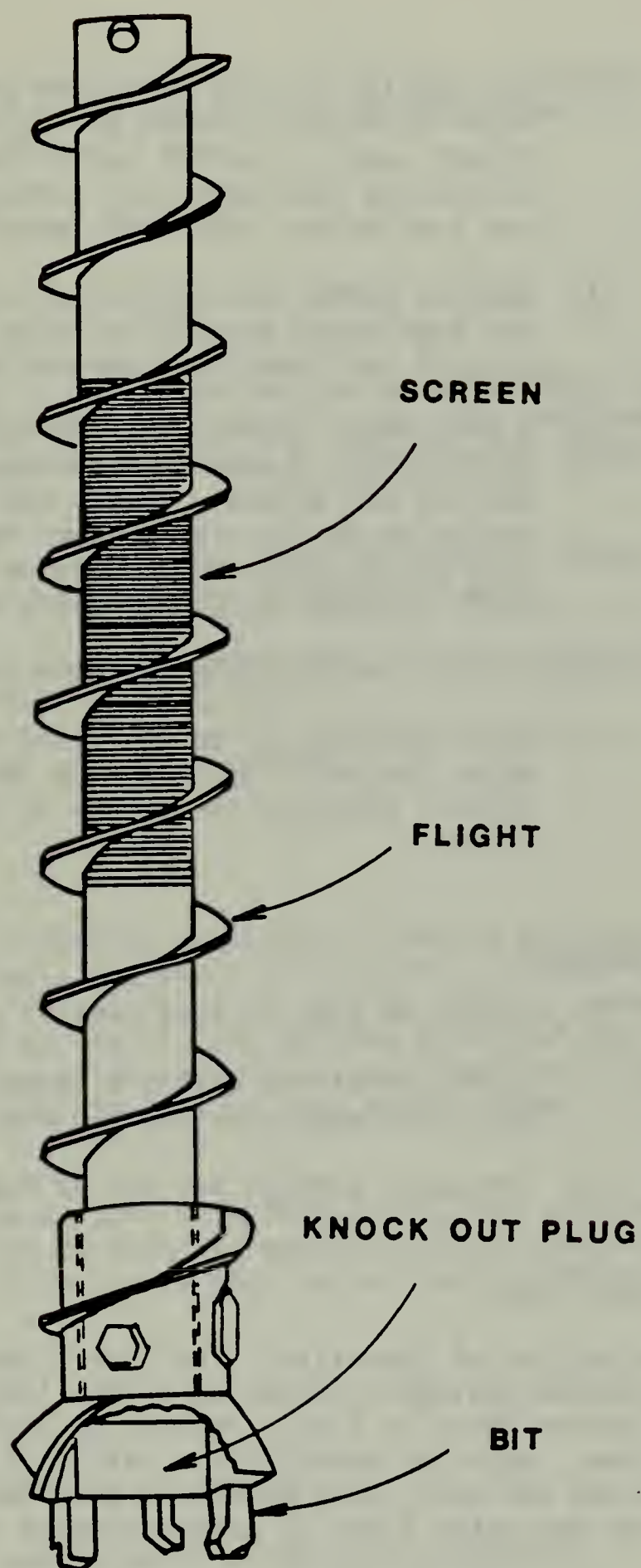


Figure 6. Keck screened, hollow stem, continuous flight auger (after Scalf et al, 1981).

- (3) The problem of hole caving in saturated, unconsolidated material, as when the solid-stem, continuous-flight auger is pulled out of the hole, is overcome by placing the casing and screen down inside the hollow stem before the augers are removed.
- (4) Natural gamma-ray logging can be done inside the hollow stem which permits defining the nature and thickness of the formations penetrated.
- (5) A grout seal can be placed around the permanent casing by attaching a cement basket above the screen before setting the assembly inside the hollow stem. Grout is placed in the annulus between the casing and hollow stem as the augers are pulled out. Grout is continuously injected or placed until all augers are removed.
- (6) Depth to water table can be accurately determined.
- (7) Water samples can be collected at any desired depth below the water table during the drilling operation without removing the augers or setting a screen and casing.

Disadvantages:

- (1) Cannot be used in hard rock.
- (2) Depth limitation varies with equipment and type of soils but approximately 150 feet is practical.
- (3) Formation samples may not be completely accurate.

4. Bucket Auger

Principles of Operation: The bucket auger consists of a relatively large (8-inch minimum diameter by 2 feet long) bucket with a cutting edge on the bottom which is slowly rotated by a square, telescoping kelley or drill stem. When the bucket fills with cuttings, it is brought to the surface and emptied. This method is good for constructing shallow wells just into the water table in unconsolidated formations.

Advantages:

- (1) No drilling water is required when either drilling above the saturated zone, or below the saturated zone in non-caving formations.

- (2) After the hole has been drilled, the setting of casing with screen and grouting the outside of the casing to form a seal is relatively easy.
- (3) Formation sampling is excellent.

Disadvantages:

- (1) The hole diameter is large; hence, the annular space is large when small diameter casing is used. This requires careful grouting and backfilling to insure water sample integrity.
- (2) In caving formations below the water table it is necessary to continuously add water to prevent caving.
- (3) Use of the bucket auger is restricted to soft formations and depths less than about 50 feet.
- (4) These rigs are not widely available.

5. Jetting

Principles of Operation: Jetting consists of pumping water or drilling mud down through a small diameter (1½ to 2-inch) standard pipe. The pipe may be fitted with a chisel bit or a special jetting screen. Formation materials dislodged by the bit and jetting action of the water are brought to the surface through the annulus around the pipe. As the pipe is jetted deeper, additional lengths of pipe may be added at the surface.

This method is acceptable in very soft formations, for shallow sampling, and when introduction of drilling water or mud to the formation is not a consideration. For this reason this method is unsuitable for a monitoring well.

Advantages:

- (1) Jetting is fast and very inexpensive.
- (2) Because of the small amount of equipment required, jetting can be accomplished in locations where it would be very difficult to get a normal drilling rig. For example, it would be possible to jet down a well point in the center of a lagoon at a fraction of the cost of using a drill rig.
- (3) Jetting numerous well points just into a shallow water

table is an inexpensive method for determining the water table contours; hence flow direction.

Disadvantages:

- (1) A large amount of foreign water or drilling mud is introduced above and into the formation to be sampled.
- (2) It is not possible to place a grout seal above the screen to assure depth-discrete sampling.
- (3) The diameter of the casing is usually limited to two inches; therefore, obtaining samples must be either by suction lift, which limits the depth of the well, air lift, bailer, or other methods applicable to small diameter casings.
- (4) Jetting is only possible in very soft formations, and the depth limitation is shallow - say 30 feet without special equipment.
- (5) Large quantities of water are often needed.

6. Drive Points (Sand Points)

Driven wells can be installed only in soft formations which are relatively free of cobbles or boulders. In this method of drilling, a 1½ or 2 inch diameter drive point is attached to a 2 inch riser pipe and driven to completion depth with a sledge hammer, drive weight, mechanical vibrator, or pneumatic hammer. The point can be typically driven to approximately 30 feet by hand and up to 100 feet if a mechanical drive weight is used. Boulders cannot be penetrated but it is easy to move the drilling rig to an adjacent position. Drive points, because of their small diameter, are typically used in areas of high water table from which water can be removed by suction pumps (e.g., pitcher pumps or centrifugal pumps). It may not be necessary for a drilling contractor to install drive points. Investigators can install them with a minimal investment in equipment and manpower.

7. Mud Rotary

Principles of Operation. A drilling fluid is pumped down the inside of the drill pipe, and then returns to the surface through the annulus between the drill pipe and the borehole wall (Figure 7). This fluid cools and lubricates the drill bit, carries the cuttings to the surface, prevents excessive fluid loss into the formation, and prevents the formation from caving. The rotating drill pipe turns the bit which cuts the formation allowing the cuttings to be flushed out.

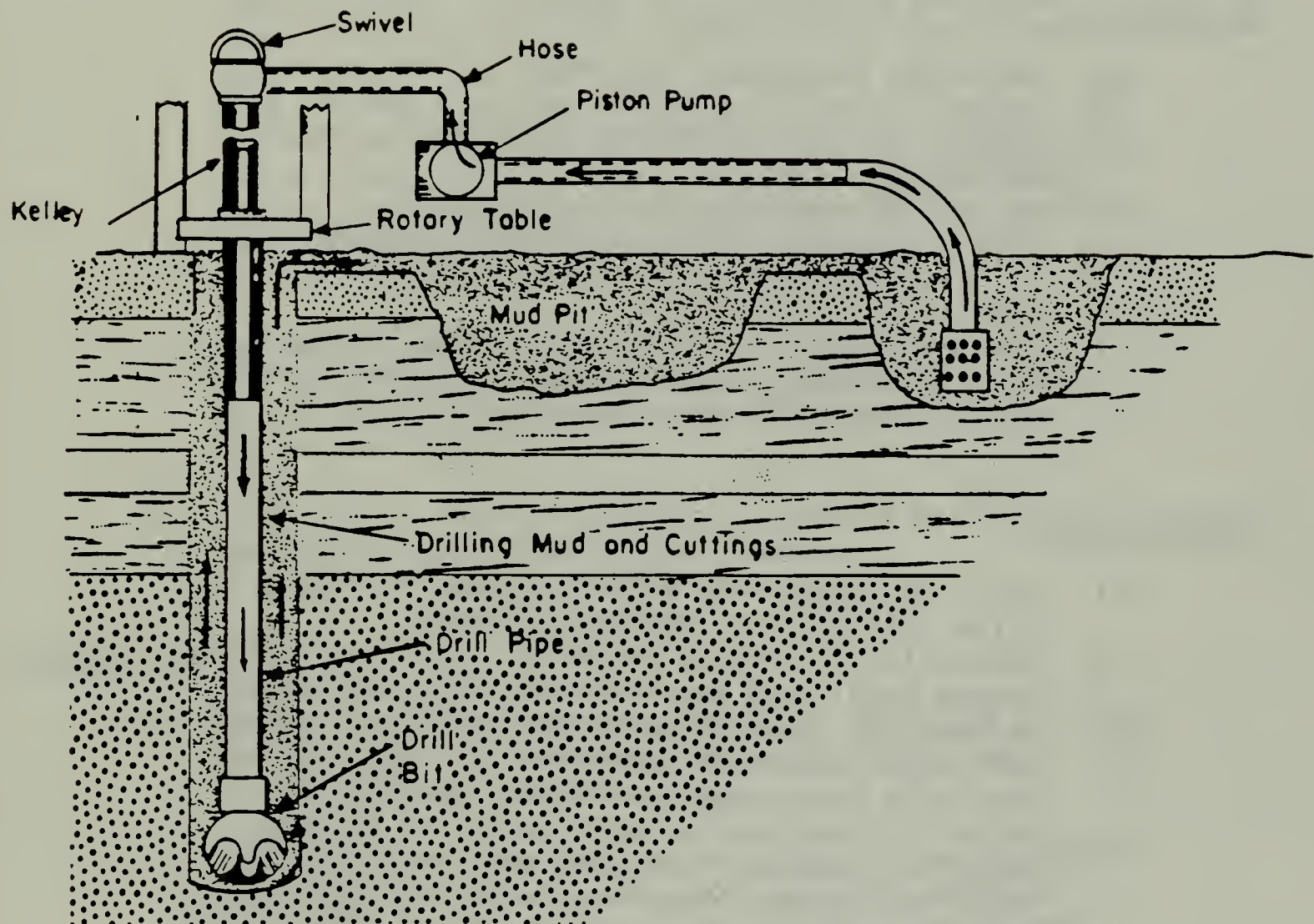


Figure 7. Mud rotary drilling. The drilling fluid (or water) is pumped through the swivel and down through the kelly which is turned by the rotary table. The mud then flows down through the drill pipe, out through the bit and back up the hole carrying cuttings which settle out of the mud in the first section(s) of the mud pit (after Scalf et al, 1981).

The drilling fluid may be clear water, water mixed with bentonite or water mixed with a biodegradable organic "mud".

Mud rotary rigs are the most common rotary rig available. Other types drilling rigs are, however, better suited for certain geologic environments and for many water quality sampling programs.

Advantages:

- (1) Available throughout the United States.
- (2) Capable of drilling all formations, hard or soft.
- (3) Capable of drilling to any depth desired for monitoring.
- (4) Casing not required during drilling.
- (5) With a skilled operator, formation logging (sampling) is fairly reliable in most formations.
- (6) Relatively inexpensive.
- (7) Electric logging of rotary drilled wells can substantially add to the accuracy of the driller's log and to water-related information.

Disadvantages:

- (1) Drilling fluid mixes with formation fluid and is often difficult to completely remove.
- (2) Bentonite (if used to minimize fluid loss) will adsorb metals and may interfere with some other parameters, thereby making this drilling method (at least the use of bentonite drilling mud) undesirable where metals are being sampled.
- (3) Organic/biodegradable additives mixed with the water to minimize fluid loss will interfere with bacterial analyses and organic-related parameters.
- (4) No information on the position of the water table, and only limited information on water-producing zones is directly available during drilling.
- (5) Circulates contaminants.

8. Air Rotary

Principles of Operation: An air-rotary rig operates in the same manner as a mud-rotary rig except that air is circulated down the drill pipe and returns) bringing the cuttings) up the annulus. Some rotary rigs are equipped to operate either with mud or air. Air rotary rigs are available throughout much of the United States and are well suited for many groundwater quality programs.

Advantages:

- (1) No drilling fluid is used; therefore, contamination or dilution of the formation water is not a factor.
- (2) Air-rotary rigs operate best in hard rock formations.
- (3) Formation water is blown out of the hole along with the cuttings; therefore, it is possible to readily determine when the first water-bearing zone is encountered.
- (4) Collection and field analysis (after filtering) of water blown from the hole can provide enough information regarding changes in water quality for some parameters such as chlorides for which only large changes in concentration are significant.
- (5) Formation sampling ranges from excellent in hard, dry formations to nothing when circulation is lost, as in formations such as some limestones or other formations with cavities.
- (6) (Air-rotary rigs are common and readily available throughout most of the United States.

Disadvantages:

- (1) Casing is required to keep the hole open when drilling in soft, caving formations below the water table. This is often a major disadvantage.
- (2) When more than one water-bearing zone is encountered and where the hydrostatic pressures are different, then flow between the zones will occur between the time when the drilling is done and the hole can be properly cased and one zone grouted off.

9. Air Drilling with Casing Hammer

Principles of Operation: A top-head drive rotary rig can be modified to accept a casing hammer. The method of drilling is the same as with air rotary except that when caving formations are encountered the casing hammer drives the casing down to prevent the hole from caving (Figure 8). The casing can be driven without withdrawing the drill pipe. This drilling method is generally excellent for constructing monitoring wells in unconsolidated formations.

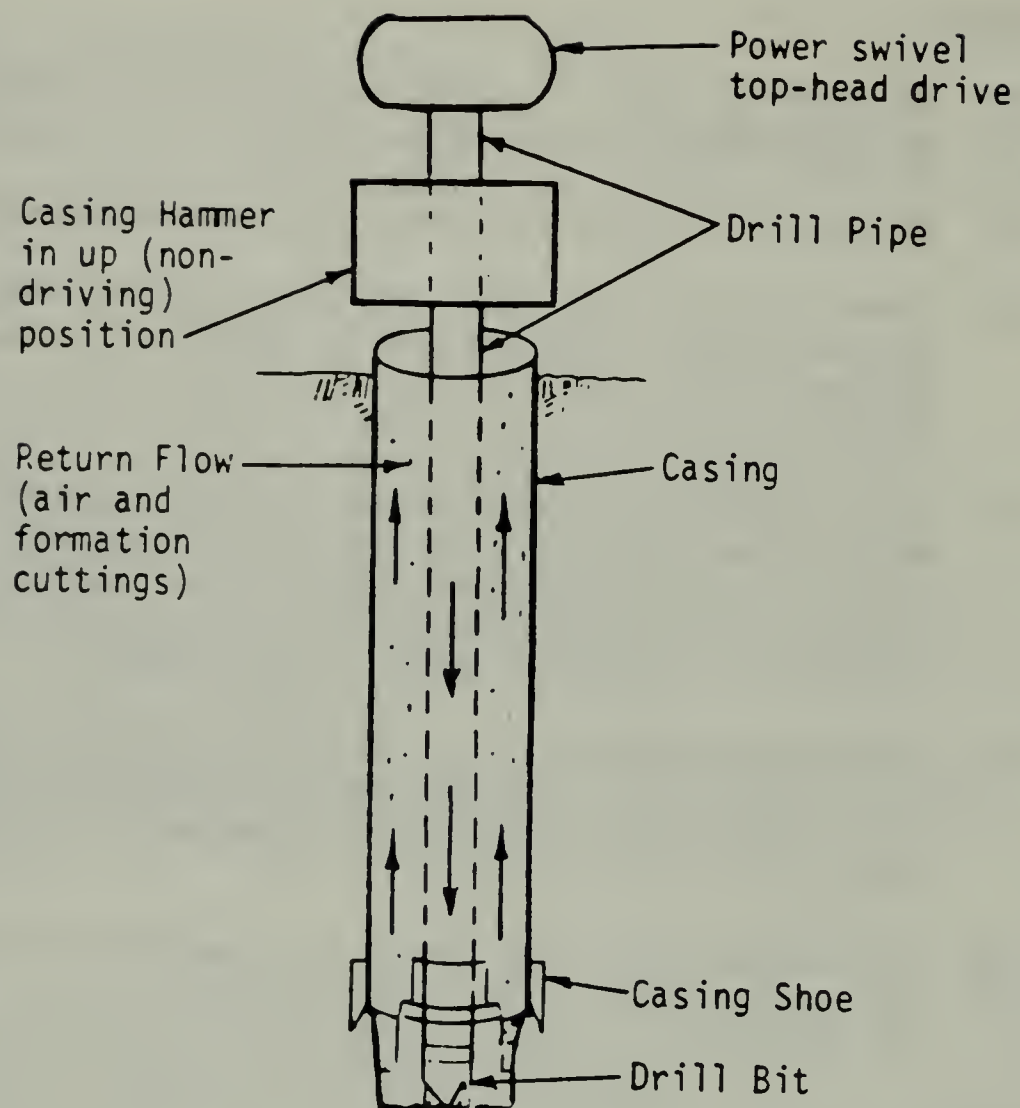


Figure 8. Air drill with casing hammer. An air drill with casing hammer operates like an air rotary drill except that in caving formations the casing can be driven to hold the hole open. The casing hammer is slipped down over the drill pipe and attached to the top of the casing and by a hammering motion, drives the casing. Usually the drill bit has drilled below the casing somewhat, but the casing shoe cuts a larger hole than the drill bit and therefore has to be driven (after Scalf et al, 1981).

Advantages:

- (1) Same advantages as with standard air rotary drilling except that soft, caving formations can be drilled.
- (2) The use of casing minimizes flow into the hole from upper water-bearing layers; therefore, multiple layers can be penetrated and sampled for rough field determinations of some water quality parameters.

Disadvantages:

- (1) Air-rotary rigs with casing hammers are not in common use throughout the United States and may be difficult to locate in some areas.
- (2) The cost per foot is substantially higher than other drilling methods.
- (3) It is difficult to pull back the casing if it has been driven very deep - say deeper than 50 feet in many formations.

10. Cable Tool

Principles of Operation: A cable tool rig uses a heavy, solid-steel, chisel-type drill bit suspended on a steel cable, which when raised and dropped, chisels or pounds a hole through the soils and rock (Figure 9). When drilling through the unsaturated zone, some water must be added to the hole. The cuttings are suspended in the water and then bailed out periodically. After sufficient water is entering the borehole to replace the water removed by bailing, then no further water need be added.

When soft caving formations are encountered, it is necessary to drive the casing as the hole is advanced to prevent collapse of the hole. Often, the drilling can be only a few feet below the bottom of the casing. Because the drill bit is lowered through the casing, the hole created by the bit is smaller than the casing; therefore, the casing (with a sharp, hardened casing shoe on the bottom) must be driven into the hole. The shoe, in fact, cuts a slightly larger hole than the drill bit. This tight-fitting drive shoe should not, however, be relied upon to form a seal from overlying water-bearing zones in water quality investigations.

Advantages:

- (1) Formation samples can be excellent with a skilled driller using a sand-pump bailer.

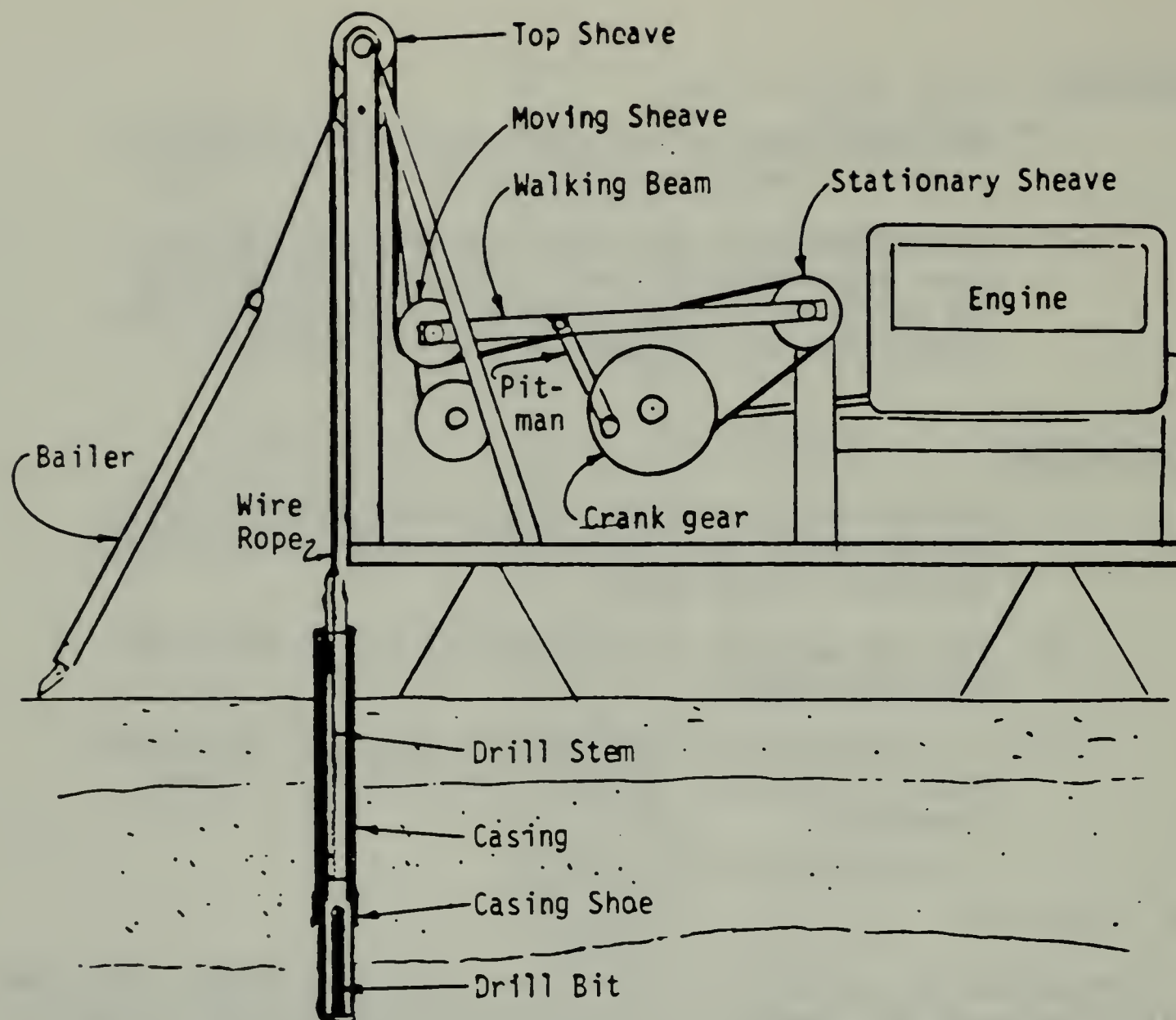


Figure 9. Cable tool drilling. The cable tool (sometimes called churn drill or percussion drill) operates as follows: rotation of the crank gear causes the pitman to raise and lower the walking beam which is anchored at the stationary sheave end. The moving sheave end of the walking beam moves up and down causing the wire rope passing over the top sheave to alternately raise and lower the heavy drill stem and bit which drills the hole. The bailer is used to remove cuttings, and the casing is driven into the hole to prevent caving in soft formations (after Scalf et al, 1981).

- (2) Information regarding water-bearing zones is readily available during the drilling. Even relative permeabilities and rough water quality data from different zones penetrated can be obtained by skilled operators.
- (3) The cable tool rig can operate satisfactorily in all formations, but is best suited for caving, large gravel type formations or formations with large cavities above the water table (such as limestones).

Disadvantages:

- (1) Drilling is slow compared with rotary rigs.
- (2) The necessity of driving the casing along with drilling in unconsolidated formations requires that the casing be pulled back to expose selected water-bearing zones. This process complicates the well completion process and often increases costs.
- (3) The relatively large diameters required (minimum of 4-inch casing) plus the cost of steel casing result in large costs compared with rotary drilling and plastic casing.
- (4) It is difficult to place a positive grout seal above the drive shoe of the casing; therefore, either the drive casing must be totally removed and the seal placed around the outside of an inner casing, or a seal must be placed above the screen but below the drive shoe. Either procedure adds to the cost and time of completion.
- (5) Cable tool rigs have largely been replaced by rotary rigs in some parts of the U.S.; hence availability may be difficult.

11. Reverse Circulation

Principles of Operation: The common reverse-circulation rig is a water or mud rotary rig with large diameter drill pipe and which circulates the drilling water down the annulus and up the inside of the drill pipe (reverse flow direction from direct mud rotary). This type of rig is used for the construction of large capacity production water wells and is not suited for small, water-quality sampling wells.

12. Special Reverse Circulation

Advantages:

- (1) The formation water is not contaminated by the drilling water.
- (2) Excellent formation samples can be obtained.
- (3) When drilling with air, immediate information is available regarding the water-bearing properties of formations penetrated.
- (4) Caving of the hole in unconsolidated formations is not as great a problem as when drilling with the normal air rotary rig.

Disadvantages:

- (1) Double-wall, reverse-circulation rigs are very rare and expensive to operate.
- (2) Placing cement grout around the outside of the casing above the screen of the permanent well often is difficult, especially when the screen and casing are placed down through the inner drill pipe before the drill pipe is pulled out.

The following table summarizing the advantages and disadvantages of commonly used drilling methods has been excerpted from API Publications 4367, Groundwater Monitoring and Sample Bias, and is intended to supplement the material already presented herein.

13. Wash Borings A wash boring is advanced partly by a chopping and twisting action of a chisel-shaped bit and partly by the jetting action of a stream of water pumped through the drill rod and out the bit (Figure 47). As the bit penetrates the formations, the washing action of the bit causes the casing to sink. Cuttings are carried to the surface by the water circulating in the annular space between the drill rod and casing. The drill string is lifted and dropped, while the bit rotates, achieving a cutting action and producing a round hole. These operations, as well as the pumping, may be performed entirely by hand; but a small motor-driven winch and pump are generally used. A closed system is implemented to recirculate the drilling water. Water is pumped from a pit into the drill string and out the bit. After circulating from the bottom to the top of the borehole, the water is conducted back to the pit where the cuttings settle out.

The drill rod is generally 2.5 to 5 cm (1 to 2 inch) black-iron pipe. Casing is required to keep the hole open in soft clays or sand and gravel but is often unnecessary in stiff clays or similar cohesive sediments. If the borehole stays open by itself, casing and screen are simply lowered and backfilled to construct a well. If casing is required to drill, slip screens are set by the casing pull-back method.

Advantages

1. Inexpensive. Light equipment. Drilling contractor not required
2. Excellent for shallow bore holes in unconsolidated sediments.
3. Can obtain vertically-spaced ground-water sample if drive point is forced ahead of borehole and pumped.
4. Drilling equipment can reach almost any site.
5. Core samples can be collected.

Disadvantages

1. Slow, especially at depth.
2. Maximum depth of 30 to 46 meters (100-150 feet).
3. Cannot penetrate boulders or wash up coarse gravel.
4. Can be used only in unconsolidated sediment.
5. Wash water can dilute formation which must be taken into account in vertical sampling.
6. Interpretation of geology from wash samples requires skill.
7. Can set only short sections of screen without difficulty.

Table 6

Advantages and Disadvantages of Commonly Used Drilling Methods
(After Gillham et al. ,1983)

ADVANTAGESDISADVANTAGESHOLLOW-STEM AUGERS

- | | |
|--|--|
| <ul style="list-style-type: none"> - Can avoid the use of foreign fluids. - Can avoid the use of lubricants. - Suitable for collecting undisturbed geologic samples (Shelby Tube, Split Spoon). - Water samples can be collected during drilling (see Destructive Sampling, Section 4.8). - Sand packs and seals can be positioned accurately. - Relatively inexpensive. - Auger rigs are mobile and are readily available. | <ul style="list-style-type: none"> - Can cause vertical mixing of formation water and geologic materials. - Possible contamination from metal components. - Limited to unconsolidated geologic materials without large rocks. - Limited to depths of about 30-50 m (100-165 ft). |
|--|--|

MUD ROTARY

- | | |
|--|--|
| <ul style="list-style-type: none"> - Can be used to any depth. - Suitable for consolidated or unconsolidated materials. - Undisturbed cores can be taken but there is some risk of contamination by drilling fluids. - Fast, relatively inexpensive and readily available. | <ul style="list-style-type: none"> - Vertical mixing caused by fluid circulation. - Invasion and contamination of the formation by drilling fluids. - Placement of sand packs and seals is generally less certain than with auger methods. - May get contamination from lubricants and metal parts - Disposing of contaminated drilling mud and the large amount of water normally required to clean and develop the installation may be a problem. - Casing required in caving or cavernous formations. |
|--|--|

Table 6 (Continued)

ADVANTAGESDISADVANTAGESCABLE TOOL

- | | |
|--|---|
| <ul style="list-style-type: none"> - Suitable for consolidated or unconsolidated materials. - Little or no drilling fluid required. - Formation samples and water samples can be collected during drilling. | <ul style="list-style-type: none"> - Potential for vertical mixing of materials as the casing is driven. - Contamination where drilling fluid is used. - Slow. |
|--|---|

DIAMOND DRILLING

- | | |
|--|--|
| <ul style="list-style-type: none"> - Can drill to any depth. - Can be used to give continuous cores of the geologic material. - Particularly useful for locating and characterizing fractures and fracture zones. | <ul style="list-style-type: none"> - Limited principally to use in consolidated materials but can also be used in highly compacted tills. - Foreign water is used which may contaminate the formation. In highly fractured material it may be difficult to remove the foreign water. |
|--|--|

AIR ROTARY

- | | |
|--|--|
| <ul style="list-style-type: none"> - Can be used to any depth in both consolidated and unconsolidated materials. - Drilling fluids are not required. - Samples of cuttings and water can be collected from the material blown from the hole. - Fast. | <ul style="list-style-type: none"> - Vertical mixing may occur along the wall of the hole. - Casing required in caving or cavernous formations. - Relatively expensive. - Air will contaminate the groundwater in the vicinity of the borehole and the samples blown from the hole. - Unadvisable in areas contaminated by toxic compounds. |
|--|--|

Use of Borehole Geophysics

The use of geophysics can greatly enhance the amount of information gained from a borehole. Each geophysical logging method is designed to operate in specific borehole conditions, involves lowering a sensing device into the borehole and can be interpreted to determine lithology, geometry, resistivity, bulk density, porosity, permeability, moisture content and to define the source, movement, chemical and physical characteristics of groundwater.

1. Spontaneous-Potential Logs: These logs are records of the natural potentials developed between the borehole fluid and the surrounding rock/soil materials. The SP log is mainly used for geologic correlation, determining bed thickness and separating non-porous from porous rocks in shale-sandstone and shale-carbonate sequences. It can be run only in open, uncased and fluid filled boreholes.
2. Normal Resistivity Logs: Normal logs measure the apparent resistivity of a volume of surrounding rock/soil. The short normals give good vertical detail and record the apparent resistivity of the mud invaded zone. The long normals record the apparent resistivity beyond the invaded zone. The radius of investigation is generally equal to the distance between the borehole current and measuring electrodes. These logs can be run only in open, uncased and fluid filled boreholes.
3. Natural-Gamma Logs: natural-gamma logs or gamma-ray logs are records of the amount of natural-gamma radiation emitted by rocks/soils. The main use of this logging method is for the identification of lithology and stratigraphic correlation. These logs can be run in open or cased, fluid or air filled boreholes. The radius of investigation extends to about 6-12 inches of the borehole wall.
4. Gamma-Gamma Logs: these logs record the intensity of gamma radiation from a source in the probe after it is backscattered and attenuated within the borehole and surrounding rocks/soils. The main uses of gamma-gamma logs are for identification of lithology and measurement of bulk density and porosity of rocks/soils. They are also used for locating cavities and cement outside the casing. The radius of investigation is about 6 inches from the borehole wall. These logs can be run in open or cased, fluid or air filled boreholes.
5. Caliper Logs: a caliper log is the record of the average borehole diameter. Its major use is to evaluate the environment in which other logs are made in order to correct for hole-diameter effects. They also provide information on lithology and borehole conditions. Caliper logs can be run in fluid or air filled, cased or open boreholes.

6. Temperature Logs: These logs provide a continuous record of the fluid temperature immediately surrounding the probe. The data can be interpreted to provide information on the source and movement of groundwater and the thermal conductivity of rocks/soils. Temperature logs are best applied in fluid filled, open boreholes although they can also be run in air filled and cased boreholes. The zone of investigation is limited to that fluid immediately surrounding the probe which may or may not be representative of the temperature in the surrounding rocks/soils.
7. Fluid-Conductivity Logs: These logs provide a measurement of the conductivity of the borehole fluid between the electrodes in the probe. When properly corrected, they provide information on the chemical quality of the borehole fluid. They are best applied in open, fluid filled boreholes.



CHAPTER 4. MONITORING IN THE UNSATURATED ZONE

The unsaturated zone refers to that region between the land surface and the deepest water table and includes the capillary fringe. The expression is somewhat erroneous since saturated regions may exist within this zone (i.e., perched water tables). The term replaces such expressions as "zone of aeration" and "vadose zone" (Lohman et al, 1972). The depth of the unsaturated zone in Massachusetts can range from a few feet to tens of feet, depending upon the amount of natural or artificial recharge and whatever pumping schemes are in effect. Reliable techniques for monitoring pollutants in the unsaturated zone are still being developed. The approach is interdisciplinary, employing techniques from soils science, geophysics, and hydrogeology.

Resistivity Methods

Resistivity methods can be used to characterize soil salinity and to delineate the areal distribution of shallow pollution plumes that increase the soil conductance. The soil particles are minerals or rock fragments which are considered insulators. Therefore, electrical charges are conducted through the pore water which contains dissolved electrolytes. The resistivity of the soil is dependent upon the concentration of dissolved electrolytes as well as the porosity and the degree of saturation of the soil.

The resistivity methods described in the Surface Geophysical Methods section can sometimes be used in the unsaturated zone. There are, however, other methods that are restricted for use within the unsaturated zone. These methods include salinity sensors and four point resistivity probes that are permanently inserted in boreholes or installed during the construction phase at facilities. The use of an electrical resistivity array for the detection of leaks from facilities is described by Kaufman et al (1981). The system uses a matrix of 25 electrodes set below the leachate collection system in a 5 x 5 pattern at 45' intervals. This allows 28 configurations for a typical Wenner resistivity survey.

Soil Water Sampling Methods

Depending upon the type of contaminant, much knowledge can be gained through examining the water content of the soil. Even when the soil is at field capacity, which is by definition when free drainage has virtually ceased and the remaining water is held in the soil by suction, water samples may be taken with the use of lysimeters.

Some of the apparatuses for acquiring soil water samples are:

- (1) Vacuum Lysimeters
- (2) Pressure-vacuum Lysimeters

- (3) Deep-pressure Vacuum Lysimeters
- (4) Organic Compound Samplers
- (5) Hollow Fiber Samplers
- (6) Membrane Filter Samplers

Of these, vacuum lysimeters and pressure-vacuum lysimeters are utilized most often. In most areas of Massachusetts the depth to the water table would not be so excessive as to require the use of deep pressure lysimeters. The remaining methodologies are largely in the experimental phase. Practical applications have yet to be clearly demonstrated, but descriptions of the equipment have been included as they may become viable techniques in the future.

1. Vacuum Lysimeter (Suction Lysimeter)

These soil moisture samplers are used to obtain samples of in situ soil water at depths of up to 6 feet. Vacuum lysimeters consist of a porous ceramic cup cemented to commercial plastic piping (Figure 10). A one-hole stopper is used as a plug for piping and neoprene tubing is inserted into the stopper. A vacuum of about 50-85 centibars is applied to the assembly by means of a vacuum test hand pump. A pinch clamp is then closed securely to seal the sampler under vacuum.

The vacuum causes the water to flow from the soil through the ceramic cup and into the sampler. As water in the soil comes into contact with the porous ceramic cup, water moves from the soil into the cup due to capillary suction. The size of the pores in the ceramic cup control the suction range under which water is extracted from the soil. The sample is recovered by opening the pinch clamp and inserting one end of the thin plastic tubing into the neoprene tube and the other end into a stopper covering a small flask. A vacuum test hand pump is inserted into the second hole in the stopper of the flask. The vacuum is applied, causing the water from the sampler to flow into the flask.

This type of lysimeter is available in various lengths and can be installed vertically or at an angle within the soil. They are designed to project slightly above the soil surface (Figure 10). Several techniques may be used to install the suction lysimeter, depending on soil and site conditions. Typically, a small hole is cored with a hand auger to the desired depth and the soil water sampler is inserted. The hole is back-filled with native soil, a soil-water slurry or silica sand. It is important that the porous ceramic cup is in intimate contact with the soil. This will facilitate the movement of soil moisture from pore spaces in the soil through the openings in the ceramic cup.

Advantages:

Vacuum lysimeters are accepted as a satisfactory apparatus for obtaining soil water samples at shallow soil depths for both research work and pollution control purposes.

With adequate moisture available, some soil moisture can be extracted from the soil at tensions equal to the vacuum which is drawn. However, if rainfall does not occur over a long period of time, the amount of soil water the vacuum lysimeter can extract at a given time will decrease due to the fact that capillary pressure increases within the soil. This causes any residual moisture to be tightly retained between the soil particles.

Freezing conditions will not damage the lysimeters and there are no maintenance problems except for protecting the exposed end of the body tube from physical damage and from being covered by debris.

Vacuum lysimeters have been demonstrated to provide samples for determining electrical conductance, calcium, magnesium, and phosphorus levels in soil water.

Limitations

Most of the limitations associated with suction lysimeters are due to problems related to the installation and operation of the porous ceramic cup. Also, the effect of the ceramic cups on the chemical quality of the sample has not been thoroughly substantiated. Their suitability for determining nitrate-nitrogen ($\text{NO}_3\text{-N}$) is questionable. The cups are composed of aluminum oxide, so control standards for aluminum must be determined beforehand if this parameter is to be measured.

Some investigators have indicated problems with clogging of the pore spaces in the ceramic cup due to suspended particles and microbial growth, while other researchers have successfully used lysimeters without any clogging. However, bacteria and suspended solids are screened out by the cup so that measurements for these parameters are not obtainable. An additional problem with lysimeters is that they cannot be used to sample volatile organics. An organic sampler in the process of development is discussed on page 60.

2. Pressure-Vacuum Lysimeter

This type of lysimeter is the one that is most commonly used in pollution monitoring. It is capable of obtaining samples from depths of up to 50 feet. The technology behind the utilization of such lysimeters has been well established. They were developed by Parizek and Lane (1970) for sampling beneath a land disposal project.

In design, pressure-vacuum lysimeters (Figure 11) are similar to vacuum lysimeters; however, there are some significant differences. Figure 11 shows that two access tubes are placed within the body tube. One tube extends from the ceramic cup to the sample bottle. The other reaches slightly below the rubber stopper and is connected on the other end to a pressure-vacuum pump and gauge. The 24-inch body tube holds a one liter sample and is designed to be buried completely within the soil.

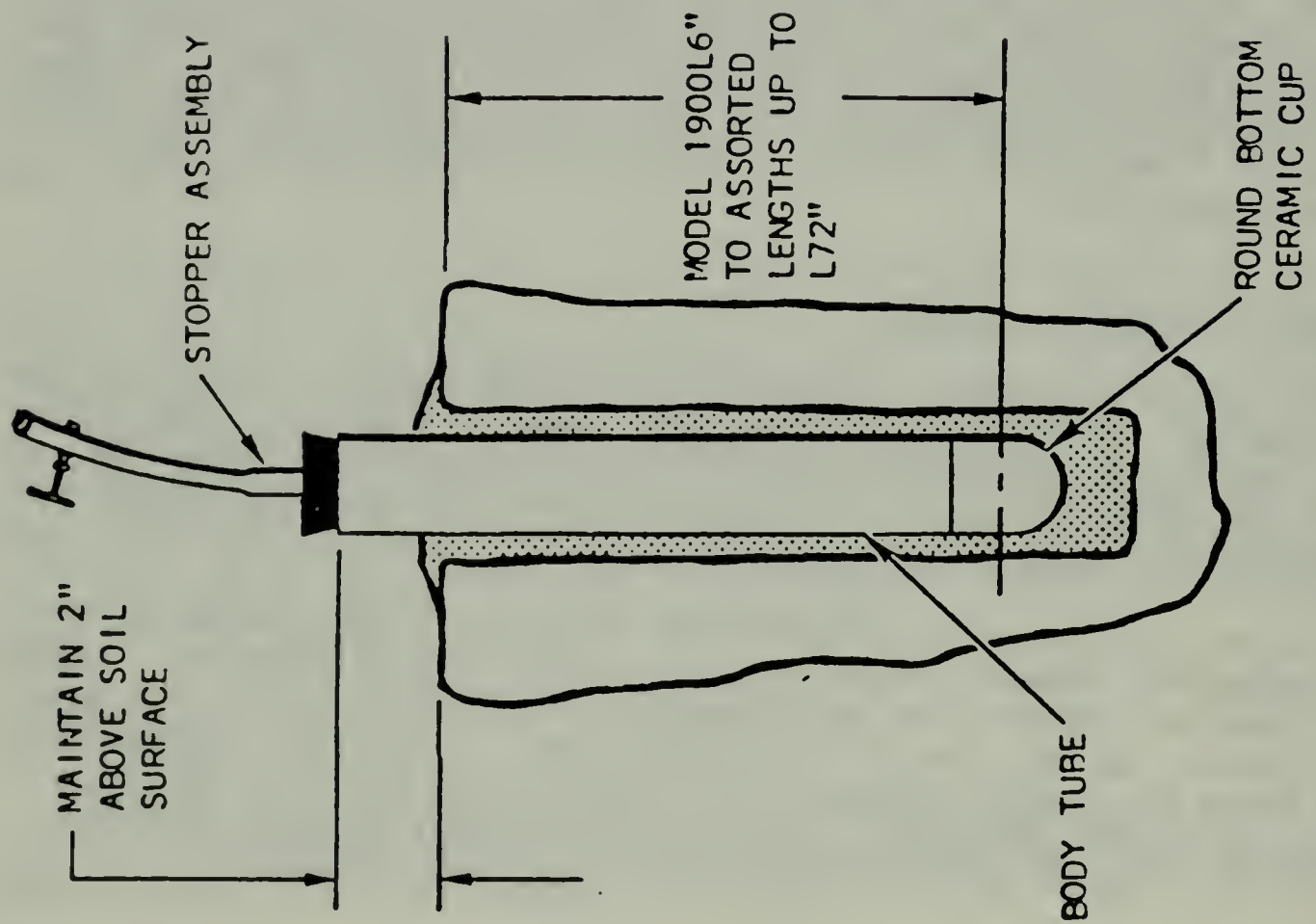


Figure 10. Vacuum lysimeter (11)

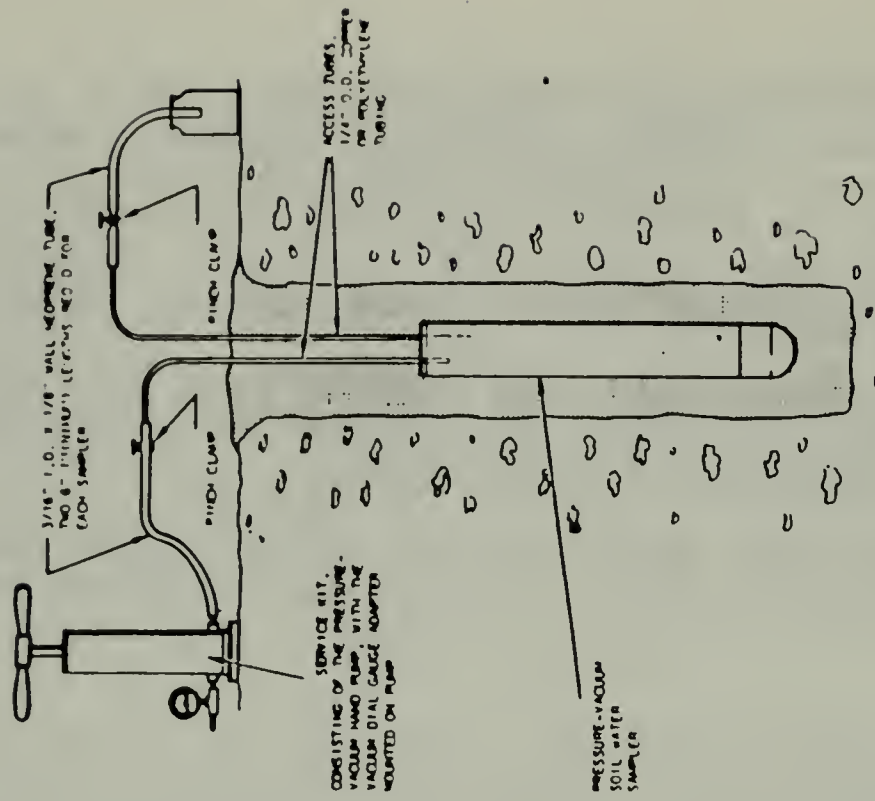


Figure 11. Pressure vacuum lysimeter

The sample is collected in the sampler tube under vacuum in a similar manner to the sample in the vacuum lysimeter. To remove the water sample from the lysimeter, air pressure from a pump or portable cylinder of air is used to force the sample into the collection flask. Thus, samples may be collected at the surface well away from the installation site.

The pressure-vacuum lysimeter is normally installed at a minimum depth of 3 feet and can be installed at depths of up to 50 feet. Close contact of the soil and ceramic cup is again the primary concern in installation of the sampler.

Advantages:

Sampling at greater depths and remote sampling ability at a central point are obvious advantages in using a pressure-vacuum lysimeter. Stacking of up to three samplers is possible in a six inch diameter hole, allowing monitoring of contaminants at different depths in the same location.

These lysimeters have shown good reliability over a long period of time and both initial costs and installation are inexpensive. Little maintenance is necessary, as in vacuum lysimeters. They are an efficient method of obtaining samples for standard water analyses if care is taken during assembly and installation.

Limitations

Limitations due to the operation of the porous ceramic cup have already been discussed under the limitations of vacuum lysimeters.

For pressure-vacuum lysimeters the only additional disadvantage appears to be that the fragility of the equipment used to recover the samples somewhat restricts the ease of sampling.

3. Deep Pressure-Vacuum Lysimeter

This sampler is a modification of the pressure-vacuum lysimeter that allows sampling at depths of up to 300'. This type of lysimeter is composed of a body tube divided into two chambers which are isolated except for two check valves in the cup assembly (Figure 12). The valves permit the delivery of the water from the soil to the upper chamber when the vacuum is applied. To remove the sample, the vacuum is released and pressure is applied. The second check valve prevents the pressure from reaching the porous cup, averting damage to the cup as higher pressures are used to obtain samples from greater depths.

Advantages:

Deep-pressure vacuum lysimeters provide an effective means of monitoring in the unsaturated zone at any depth, but particularly at greater

depths. Advantages outlined for other types of lysimeters are also applicable for deep pressure lysimeters.

Limitations

If the gas pressure used to obtain the sample is excessive, only partial recovery of the sample is obtainable due to the loss of dissolved gases caused by bubbling of the water. The pressure should be gradually increased until the sample flows smoothly.

Deep-pressure vacuum lysimeters can only be installed one unit to an observation hole, in contrast to the multiple unit installation described for pressure-vacuum lysimeters.

4. Organic Compound Sampler

A methodology for sampling organic compounds in the unsaturated zone was recently developed at Robert S. Kerr Environmental Research Laboratory (Pettyjohn, 1981). The device consists of a soil solution sampler, a purging apparatus and a trap (Figure 13). It is similar in design to a pressure-vacuum lysimeter.

The sampler consists of a porous ceramic cup and teflon pipes, stopper, and tubing. The purging apparatus is made of borosilicate glass and the purging gas used is high purity, oxygen-free nitrogen. The trap is constructed of a porous polymer and packed in a stainless steel tube which is stopped with silane-treated glass wool.

The purging apparatus should be thoroughly cleaned using acetone and distilled water and baked at 105° to 108°C for an hour before using. Distilled water is used in the field for rinsing between samples.

With this apparatus, the collection of the samples is rather complicated. The exhaust section of the collection tube must be checked beforehand to see if any solution has leaked in. Then, the exhaust tube is clamped tight, valves A and B opened, and a 5 to 10 ml sample is collected. The exhaust tube must then be reopened to collect any of the samples that may have volatilized in the sampler. Nitrogen gas is passed through the solution to purge the volatile organics from the solution. The traps are then capped for analysis. Storage at -20°C is necessary if analysis does not occur within 6 hours.

5. Hollow Fiber Sampler

These samplers are a type of soil-water suction sampler. They are composed of semi-permeable fibers which are produced from a non-cellulosic polymer solution and function as a molecular sieve in the soil-water solution. Substances with a molecular weight of 500 to 300,000 can be excluded from the sample.

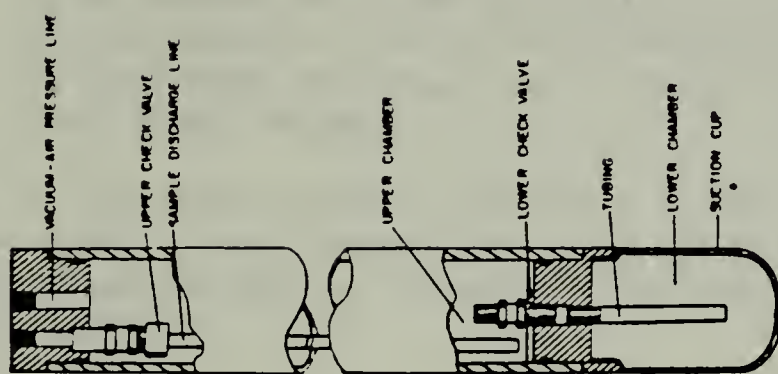


Figure 12. Deep pressure vacuum lysimeter

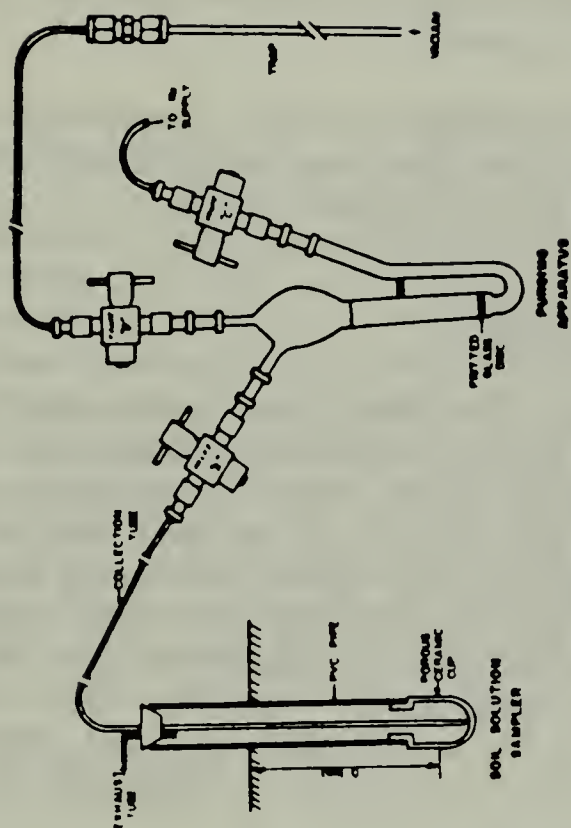


Figure 13. Device for obtaining highly volatile organic compounds from the unsaturated zone.

The fibers have been demonstrated to extract samples for analysis at a rate equal to suction lysimeters.

Hollow fiber samplers have not been proven as a viable method for obtaining in situ soil water samples for pollution monitoring. Their technology is still in the developmental stage.

6. Membrane Filter Sampler

Another methodology for extracting soil water samples within the unsaturated zone, which is largely in the experimental stage, is that of membrane filter samplers. Glass fiber wicks are inserted horizontally into glass fiber collectors which are placed in a hole. Subsequent filters and a sampling tube are also placed within the hole before it is backfilled. These samplers operate on the principle of capillarity. Soil water is drawn into the fiber wicks when a vacuum is applied to the filter holder assembly. Preliminary field tests indicate that this method provides a favorable sampling rate for extraction of soil water samples.

CHAPTER 5. MONITORING IN THE SATURATED ZONE

The construction details and general information regarding monitoring wells have been reviewed in Chapter 3. If the site hydrogeology has been found to be fairly simple (i.e. groundwater flow in the vicinity of the site is essentially horizontal, the unconsolidated deposits are fairly homogeneous, and the bedrock geology is not complex), then multi-purpose monitoring wells to measure water table elevations and water quality would be the most cost-effective approach to groundwater monitoring. When the site hydrogeology is complex and the contaminant species are variable, depending upon the type of sampling equipment utilized (dedicated vs. universal), it may be necessary to install separate wells for sampling water quality and piezometric head. If contaminants have migrated to different depths in the aquifer, multi-level sampling may be required. As one would expect, site complexity and groundwater monitoring costs are directly proportional to each other, thereby emphasizing the need for a detailed hydrogeological study.

Specific Requirements for Monitoring Wells

The following information on specific requirements, for monitoring wells and their development has been taken from A Manual of Ground-water Sampling Procedures (Scalf et al, 1981) and is used with permission from the National Water Well Association.

Because the location, design, and construction of the monitoring wells are usually the most costly and non-repeatable factors, it is extremely important that the well construction be accomplished properly at the outset.

The primary objectives of monitoring wells are:

- (a) to provide access to groundwater;
- (b) to determine which pollutants are present in the groundwater and at what concentrations;
- (c) to determine the areal and vertical distribution of pollutants.

In order to accomplish these objectives in the most competent and cost-effective manner, consideration must be given the proper well design and construction method that will best fit the specific objectives and the hydrogeologic conditions.

1. Location

The general criteria for locating monitoring wells depends upon the site specific hydrogeology. Occasionally, a location which is highly desirable from the perspective of groundwater flow presents unusual problems in design and construction of the monitoring well. The effect that location may have on well design and construction can best be appreciated by understanding basic design criteria and drilling methods.

2. Diameter

The diameter of the casing for monitoring wells should be just sufficient to allow the sampling tool (bailer or pump) to be lowered into the well to the desired depth. The diameter of the hole into which the casing is placed must be at least sufficiently large for the casing to fit and, where a grout seal is to be employed, the casing must be at least 2 inches larger.

Casings and/or holes drilled much larger than the necessary minimum can, in fact, have undesired effects on the data. For example, in formations of very low permeability, the excessive storage in an unnecessarily large boring can cause the water level in the boring to be erroneously low for days or even weeks. Also, because it is usually necessary to remove water standing in the well before taking a sample of the formation water, excessive storage can complicate the water sampling procedure.

3. Depth

Except in the case of certain flow-through monitoring wells designed to monitor the entire depth of the aquifer, the intake part of a monitoring well should be limited to specific depth ranges.

Existing water supply wells in an area to be monitored are often used as sampling points. Substantial care must be exercised when this is done and the results are often questionable. Water supply wells are constructed to produce a given quantity of water; hence, they may be screened throughout a thick aquifer, through several permeable layers of an aquifer, or sometimes through two or more aquifers or discrete water-bearing layers. When this situation exists, it is probable that the hydrostatic heads are different between different layers. Under non-pumping conditions this interconnection permits water from the layer with the higher head to flow through the well and into the formation with the lower head. This can occur between layers of different permeability separated by only a few feet of low permeability material. This condition can have substantial effect on the concentration of a pollutant obtained by pumping for a short time before sampling.

Therefore, it is important that monitoring wells be constructed to be depth-discrete and to sample only from one discrete layer without interconnection to other strata. In order to assure that this depth-discrete requirement is met, provisions for placing cement grout above and, if necessary, below the well screen on the outside of the casing must be made in the design of the wells.

Commonly (especially when sampling for contaminants lighter than water), it is desirable to sample at the top of the saturated zone in an unconfined aquifer. The screen or intake part of the well should then extend from a few feet above to a few feet below the anticipated position

of the water table to allow for future water table fluctuations. Often, under semi-confined aquifer conditions, the water will rise in the well above the top of the more permeable layer and above the top of an improperly positioned screen. Care must be exercised in these cases to extend the screen high enough to be above the water level in the formation; otherwise, light organics or other contaminants could be undetected or at least not properly quantified. On the other hand, a contaminant can migrate along fairly restricted pathways and go undetected by depth discrete wells which are not completed at the proper depth. This danger is particularly present in a geologic environment of highly stratified formations, and in fractured rock formations.

4. Intake Portion of Monitoring Wells

That part of the well through which water enters the casing must be properly constructed and developed to avoid subsequent sampling problems. Commercially made well screens used in water supply wells are recommended for most monitoring wells even though well efficiency is not a primary concern. Other choices are sawed or torchcut slots in the well casing to let the water flow in.

Design criteria for the intake part of the well are:

- (a) The screen or intake part should have sufficient area to permit the easy inflow of water from the formation.
- (b) The slot openings should be just small enough to keep most of the natural formation out, but as large as possible to allow easy flow of water.
- (c) The well should be developed (see Page 67).

5. Well Casings

As noted earlier, sampling equipment, including well casings, should be constructed of materials that have the least potential for affecting the quality parameters of the sample. The usual dilemma for the field investigator is the relation between cost and accuracy. Obviously, PVC is far less costly than teflon, which is a major consideration when contemplating well construction for a large scale groundwater monitoring effort. On the other hand, bleeding of organic constituents from PVC cements, as well as adsorption, poses a significant potential for affecting the quality of samples where the contaminants under consideration may be in the parts per billion range.

In many situations, it may be necessary to compromise some accuracy with cost, particularly in regard to the selection of casing materials used in well construction. For example, if the major contaminants are already defined and they do not include substances which might bleed from PVC or cemented joints, it might be reasonable to use wells cased with the less expensive and readily obtainable PVC. Or, wells constructed of less than optimum materials might be used with a reasonable level of confidence

for sampling if at least one identically constructed well was available in a nearby, uncontaminated part of the aquifer to provide groundwater samples for use as "blanks". Obviously, such a "blank" will not address the problems of adsorption on the casing material nor leaching of casing material induced by contaminants in the groundwater. Careful consideration is required in each individual case, and the analytical laboratory should be fully aware of construction materials used.

The materials generally available are teflon, stainless steel, polyvinylchloride (PVC), galvanized steel, and mild steel. Each type of material has advantages and limitations. Where expense is not limited and when sampling will be conducted for trace metals or organic compounds, stainless steel is recommended. Teflon materials are extremely expensive but considered inert. PVC has many advantages including low cost, excellent availability, light weight, and ease of manipulation, and is the most commonly used material. There are some questions about organic chemical sorption and leaching that are currently being researched. The low crushing strength of PVC may limit the depth of installation. Mild steel screens and casing can be very good for organic chemical determinations when properly cleaned. Cleaning is required because oil based preservatives and oil used during thread cutting may contaminate samples. Metal pipe, however, may corrode and release metal ions or it can chemically react with organic constituents. This is considered by some to be less of a problem than that of PVC material. Galvanized steel is not recommended for metal analyses because zinc and cadmium levels in the sample may be elevated as a result of the zinc coating of the pipe.

Appendix I includes copies of three published lists of chemical resistance of piping materials. In both cases, a range of concentrations and temperature limits are given. Where concentration levels are omitted, the value is 100%, or the commercially practical upper concentration limit.

Care must be given to preparation of the casing and well screens prior to installation. As a minimum, both should be washed with a detergent and rinsed thoroughly with clean water. Care should also be taken that these and other sampling materials are protected from contamination by using some type of ground cover such as plastic sheeting for temporary storage in the work area.

6. Cross Contamination Prevention During Drilling

All drilling and well construction equipment that will be in contact with the borehole should be free of contaminants that may be introduced into the borehole while a well is being constructed. Drilling equipment such as augers, drill rods, and fluid recirculation pumps, hoses and pits should be thoroughly cleaned before drilling commences, after each borehole is drilled, and when all drilling is complete.

Appropriate cleaning techniques include methanol, steam cleaning and detergent/ water scrubbing, or other approved methods. Chemical cleaners

such as hexane or acetone can introduce contaminants and therefore rinse water should be analyzed or followed with a detergent wash and clean water rinse.

All mixing/cooling water and wash/rinse water should be tested for parameters to be monitored in the groundwater.

Monitoring Well Development

Well development is the process of cleaning the face of the borehole and the formation around the outside of the well screen to permit groundwater to flow easily into the monitoring well. During any drilling process the side of the borehole becomes smeared with clays or other fines. This plugging action substantially reduces the permeability and retards the movement of water into the well screen. If these fines are not removed, especially in formations having low permeability, it then becomes difficult and time consuming to remove sufficient water from the well before obtaining a fresh groundwater sample because the water cannot flow easily into the well.

In the construction of high capacity production type water wells, the development process is an important step to assure maximum hydraulic efficiency. Even though hydraulic efficiency is not a primary consideration in the construction of monitoring wells, nevertheless, development should be performed (1) to insure taking a representative sample of formation water, and (2) to speed up the sample collection process.

Development is required to restore the natural permeability of the formation adjacent to the borehole to permit the water to flow into the screen easily. It is also necessary to remove the clay, silt and other fines from the formation so that during subsequent sampling the water will not be turbid or contain suspended matter which can easily interfere with chemical analysis.

The development process is best accomplished for monitoring wells by causing the natural formation water inside the well screen to move vigorously in and out through the screen in order to agitate the surrounding clay and silt, and move these fines through the screen. The use of water other than the natural formation water is not recommended.

Methods suitable for the development of monitoring wells are as follows:

1. Surge block

A surge block is a round plunger with pliable edges such as belting that will not catch on the well screen. Moving the surge block forcefully up and down inside the well screen causes the water to surge in and out through the screen accomplishing the desired cleaning action.

Surge blocks are commonly used with cable-tool drilling rigs, but are not easily used by other types of drilling rigs.

2. Air Lift

Compressed air pumped down a pipe inside the well casing can be used to blow water out of the monitoring well. If air is applied to the well intermittently and for short periods, then the water is only raised inside the casing rather than blown out and will fall back down the casing causing the desired back washing action. Finally, blowing the water out will remove the fines brought into the screen by the agitating action.

Considerable care must be exercised to avoid injecting air into the well screen. Such air can become trapped in the formation outside the well screen and alter subsequent chemical analyses of water samples. For this reason, the bottom of the air pipe should never be placed down inside the screen.

Another restriction on the use of air is the submergence factor. Submergence is the number of feet of water above the bottom of the air pipe while pumping (blowing water out) divided by the total length of the air pipe. Submergence should be on the order of at least 20 percent, which may be difficult to achieve with many shallow monitoring wells.

3. Bailer

A bailer sufficiently heavy that it will sink rapidly through the water can be raised and lowered through the well screen. The resulting agitating action of the water is similar to that caused by a surge block. The bailer, however, has the added advantage of removing the fines each time it is brought to the surface and dumped. Bailers can be custom-made for small diameter wells, and can be hand-operated in shallow wells.

4. Surging by Pumping

Starting and stopping a pump so that the water is alternately pulled into the well through the screen and back-flushed through the screen is an effective development method. Periodically pumping to waste will remove the fines from the well and permit checking the progress to assure that development is complete.

Any method that develops a monitoring well by backwashing should be avoided because of the substantial dilution or alteration of formation-water which would occur. Also, care should be taken not to create a large cone of depression during well development. This could cause contaminants from other zones to migrate toward the well.

In conclusion, development of monitoring wells, although often overlooked, is an important function of the well construction in order to facilitate future sampling and to obtain samples free of turbidity.

Observation Wells

A triangulation of wells installed within the same hydrogeologic unit (Figure 14) is necessary to define the local horizontal component of groundwater flow. Therefore, in the absence of other site specific information, a minimum of three observation well installations are necessary to describe the general direction of groundwater flow in a simple hydrogeologic setting. Additional wells may be required in order to measure the vertical component of flow.

Monitoring Wells

The number of monitoring wells required is site specific. Generally, large sites with complex hydrogeology will require a greater number than small, hydrogeologically simple sites. Monitoring wells should be installed downgradient and upgradient of the waste disposal site in water-bearing zones which could transmit contaminants, and in water-bearing zones used as a source of water supply. In the zones which could transmit contaminants, monitoring provisions at strategic points throughout the vertical depth of the aquifer zone should be provided. The final number of well installations is determined by site specific conditions and/or monitoring requirements. See Table 7 for types of installations and their benefits.

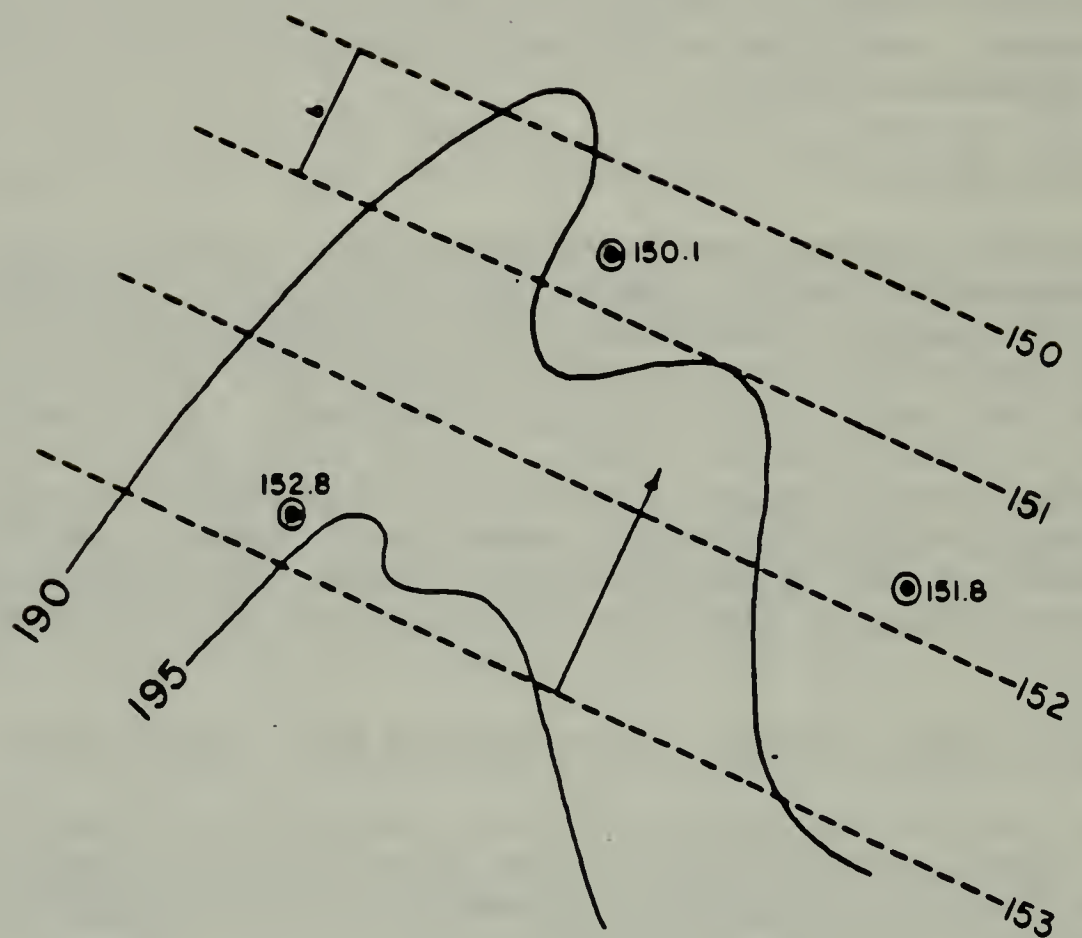
Procedures and Techniques for Monitoring Well Installation

As part of any scope of work for installing and sampling monitoring wells, a detailed discussion by the consultant of procedures and techniques for the following items should be mandatory when the potential for litigation exists. Those items include:

- a) Well construction;
- b) Well development;
- c) Decontamination of soil and water sampling equipment;
- d) Decontamination of drilling equipment;
- e) Use of drilling water;
- f) Use of drilling muds;
- g) Sample collection;
- h) Sample preservation, storage, and shipment;
- i) Analytical procedures, including quality control and assurance techniques;
- j) Chain of custody control.

Use of Field Testing Equipment

Knowledge of the subsurface materials and the quality of water encountered as the well is being constructed is highly desirable. In some instances this information is imperative because such knowledge can affect



KEY

- MONITORING WELL INSTALLATION
 - 150.1 PIEZOMETRIC OR WATER TABLE ELEVATION
 - GROUNDWATER FLOW HORIZONTAL DIRECTION
 - PIEZOMETRIC OR WATER TABLE CONTOURS
 - LAND SURFACE CONTOURS IN FEET (VERTICALLY)
- GRADIENT = $\frac{151-150}{b}$
 b = HORIZONTAL DISTANCE BETWEEN CONTOURS (FT.)

Figure 14. Monitoring well triangulation (after Mooij and Rovers, 1975).

Table 7

Advantages and Disadvantages of the Main Types of Sampling Installations
(After Gillam, et al., 1982)

SINGLE-LEVEL INSTALLATIONS

Single-level installations contain a single inlet interval for each bore-hole in which an installation is implanted (Figure 15).

- Suitable in any type of formation.
- Simple design.
- The installation itself, and where applicable the packing and sealing materials, can be implanted more easily than in the multilevel installations.
- No problems of vertical communication between sampling points due to leaky seals.
- Maximum permissible diameter is limited by size of borehole only. Common sizes vary from 1.2 to 15 cm ($\frac{1}{2}$ - 6 in.) for monitoring installations.
- Most common sizes of installation, 5 - 10 cm (2 - 4 in.), do not restrict the choice of sample collection methods.
- No information can be obtained regarding vertical distributions of groundwater constituents from a single installation (piezometer nests can be used for this purpose but at a much higher cost than multilevel installations).
- High cost per sampling point (especially at great depths) as compared to multilevel installations.
- Contaminated water may by-pass installations with short screened intervals. The problem is also present, but to a lesser extent, in multilevel installations.
- In most situations, long-screened installations provide concentration and hydraulic-head values that are spatially averaged over the length of the screen. Therefore, they may not give accurate measurements of maximum concentrations.
- Because of possible dilution in the well, long-screened installations can be used to confirm the present, but not the absence of a contaminant.
- Long-screened installations can contribute to aquifer contamination by providing a passage from contaminated zones to uncontaminated zone.

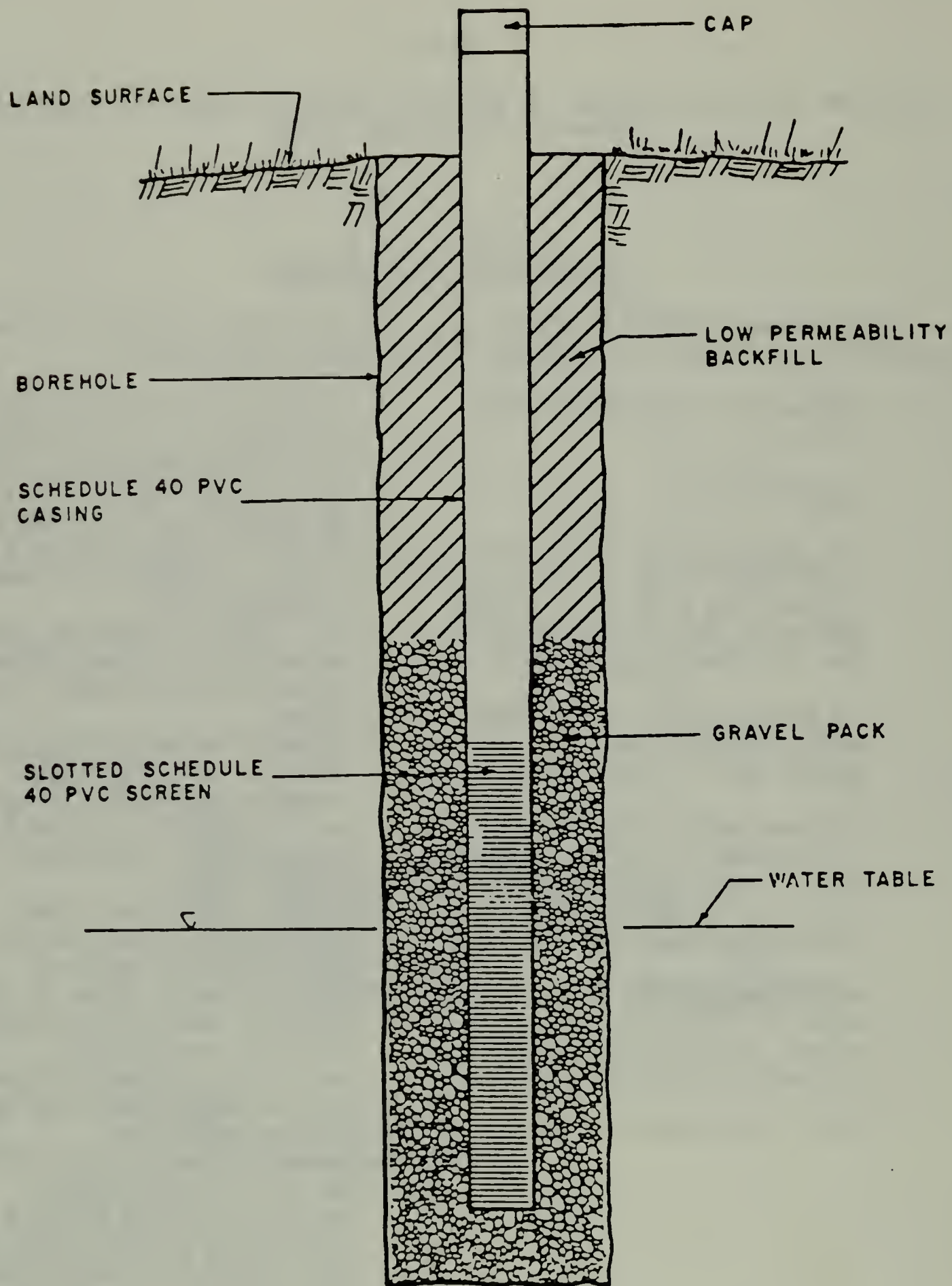


Figure 15. Typical monitoring well screened over a single vertical interval (after U.S. Environmental Protection Agency, 1977).

Table 7 (Continued)

MULTILEVEL INSTALLATIONS

In recent years, the need to obtain detailed information on the vertical distribution of contaminants, combined with the escalating cost of drilling, has led to the development of multilevel sampling installations. These installations offer the possibility of sampling the groundwater at more than one depth in a single borehole.

- Provide information on vertical distribution of groundwater constituents.
- Lower cost per sampling point than single-level installations, especially for large numbers of sampling points at great depths.
- In general, only small volumes of water need to be removed to purge the installation because of the usually small diameters.
- The installation itself, and where applicable the packing and sealing materials, are more difficult to place than for single-level installations.
- The short screened-intervals commonly used in many multilevel installations can miss small zones of contaminated water in heterogeneous materials. The likelihood of this problem can be reduced considerably by using reconnaissance methods (e.g., destructive sampling).
- Possibility of vertical communication between sampling points due to leaky seals. Problems of leaky seals can occur in single-level installations, but the consequences are usually less severe than for multilevel installations.

ADVANTAGESDISADVANTAGES"Flow-through" Wells

Flow-through wells are of fairly small diameter (maximum of a few inches), and are provided with a long screen, extending from above the water table to some pre-determined depth in the formation.

Table 7 (Continued)

<u>ADVANTAGES (Continued)</u>	<u>DISADVANTAGES (Continued)</u>
<ul style="list-style-type: none"> - Cheaper than most other multi-level installations. - Simple design and operation. - Can be installed as easily as single-level installations. - The number of sampling points per installation is not limited by the diameter of the borehole. - If the flow-through assumption is valid, there is no need to flush the installation and samples that are representative of a given depth can be obtained with a simple depth specific sampler. 	<ul style="list-style-type: none"> - Basic underlying assumption that water will flow through the well screen without having its course altered cannot be supported, for most natural systems. - Suitable only in hydraulically homogeneous formations with no vertical gradient. - The concentration and hydraulic head values are spatially averaged over the length of the screen. Therefore, they may not give accurate measurements of maximum concentrations. - Can be used to confirm the presence, but not the absence of a contaminant, because of possible dilution in the well. - Can contribute to aquifer contamination by providing a passage from contaminated zones to uncontaminated zones.

Multiple-Piezometers (Figure 16)

- | | |
|--|---|
| <ul style="list-style-type: none"> - Simple design and operation. - Less expensive than piezometer nests of corresponding number of sampling points, and less expensive than most other multi-level installations. | <ul style="list-style-type: none"> - Difficulty of installation may increase with number of piezometers per borehole. - Number of sampling points, (i.e., piezometers) per borehole is restricted by the diameter of the individual piezometers, and by that of the borehole. - Bundle piezometers have a higher risk of hydraulic connections between sampling points where seals are required and are therefore most suitable in cohesionless formations that will collapse around the tips. |
|--|---|

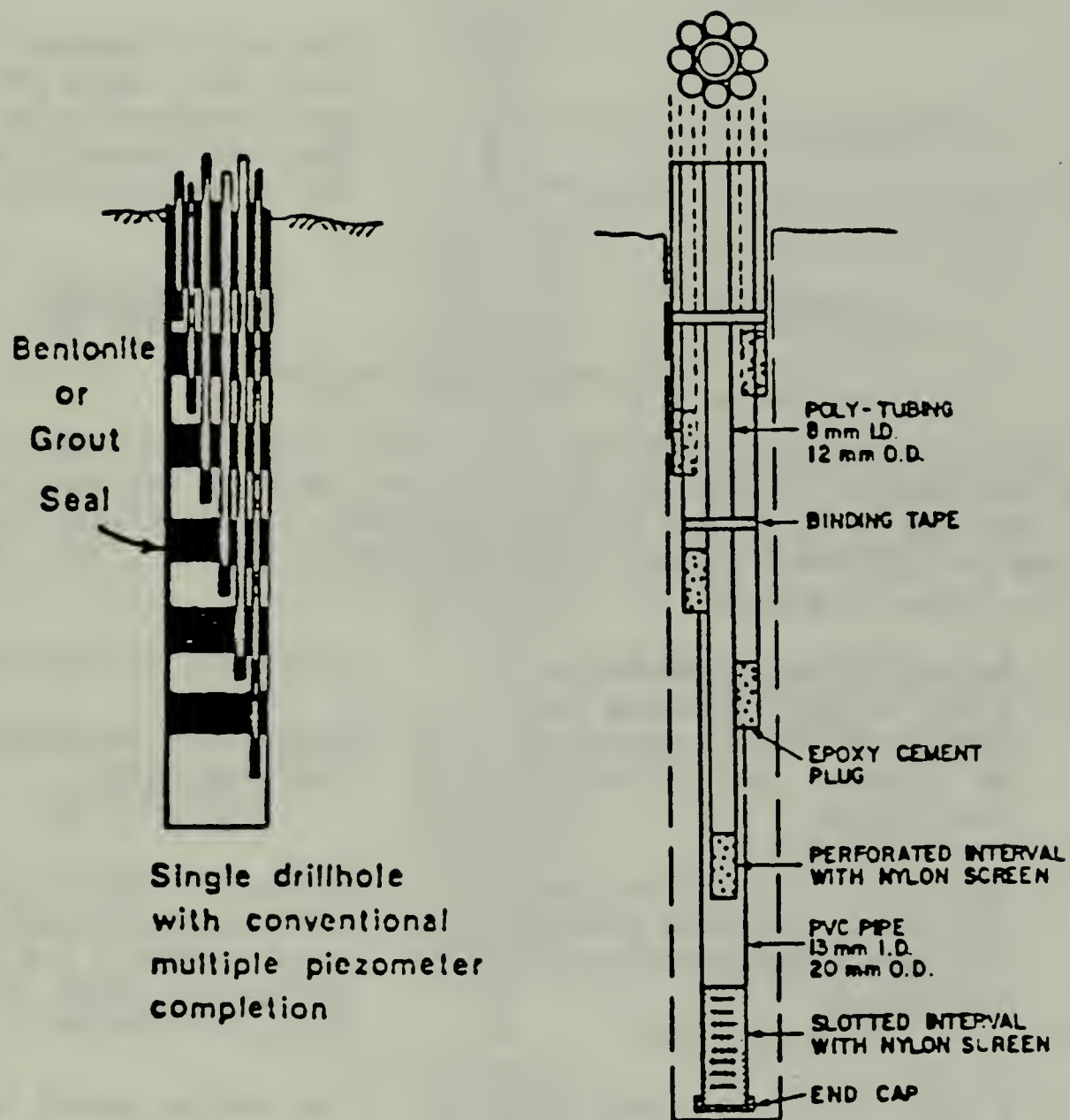


Figure 16. Multiple piezometers in a single borehole
 a) standpipe piezometers installed individually in the borehole, and b) a bundle of narrow-diameter piezometers (after Gillham, 1983).

Table 7 (Continued)

Multiple-Piezometers (Continued)

- The choice of sample collection methods is usually severely restricted by the commonly small piezometer diameters.
- The small diameters of the individual tubes provide a small storage volume and thus they are generally of limited use in fine-grained materials.

ADVANTAGESDISADVANTAGES

Gas-Drive Installations

This type of multilevel sampling installation incorporates the sample collection method (gas-drive) as an integral part of the sampling installation. Devices of this type which are suitable for multilevel groundwater sampling are available commercially from BarCad Systems, Inc., and Timco Mfg. Co., Inc. (Figure 17).

- | | |
|---|---|
| <ul style="list-style-type: none"> - Potential for cross-contamination is small because the sample-collection method is an integral part of the installation. - Operation is relatively easy and safer than most other installation for hazardous contaminants. - Little flushing is necessary because there is little mixing between incoming water from the formation, and stagnant water. | <ul style="list-style-type: none"> - Difficult to install properly. - Moderately expensive per sampling point. - Number of sampling points is limited by diameter of borehole. Commonly 3-4 sampling points for 15 cm (6 in.) borehole. - The device cannot be retrieved for servicing or repairs. If malfunctions occur, the sampling point is lost. - Hydraulic head measurements are of questionable value because of the presence of check-valves. - The choice of sample collection method is restricted to gas-drive (and suction-lift for shallow water tables). |
|---|---|

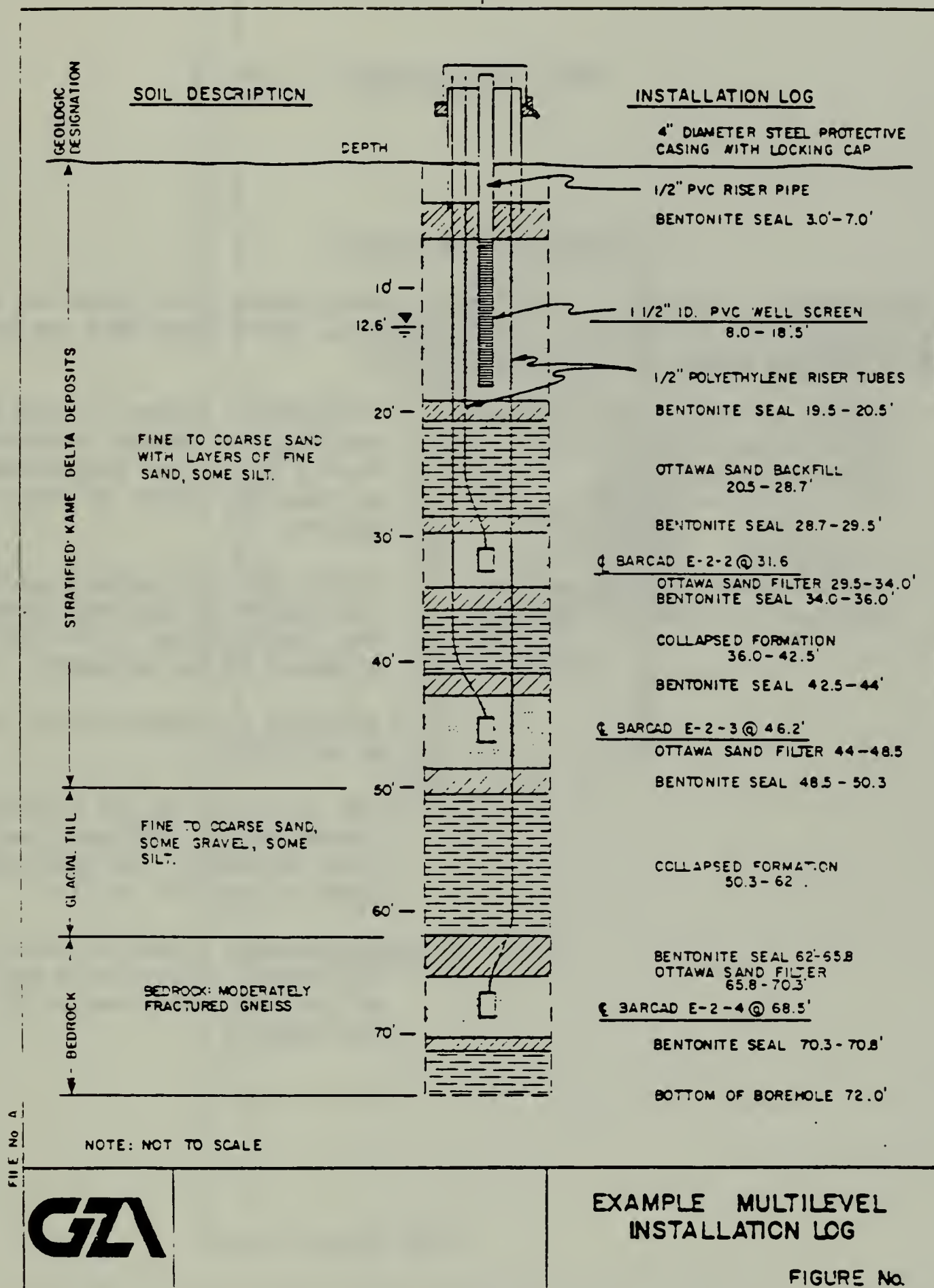


Figure 17. Gas drive installations.

Table 7 (Continued)

Multiple-Port Casings

Multiple-port casings are multilevel installations which make use of a single casing (pipe) fitted with openings (ports) which lead into the formation at several depths (Figures 18 and 19).

- Except for the Westbay system, the cost per sampling point is relatively small.
- The Westbay system is very expensive, but becomes economically viable for large numbers of sampling points at great depths.
- Seals between screens can be provided by permanent packers
- Except for the Westbay system, the number of sampling points per installation is limited by diameter of the borehole.
- Assembly and implantation can be difficult.
- The operation of the Westbay system can be difficult and time consuming, and requires special operator skills.
- The Westbay system is prone to mechanical difficulties because of the down-hole complexity of the system.

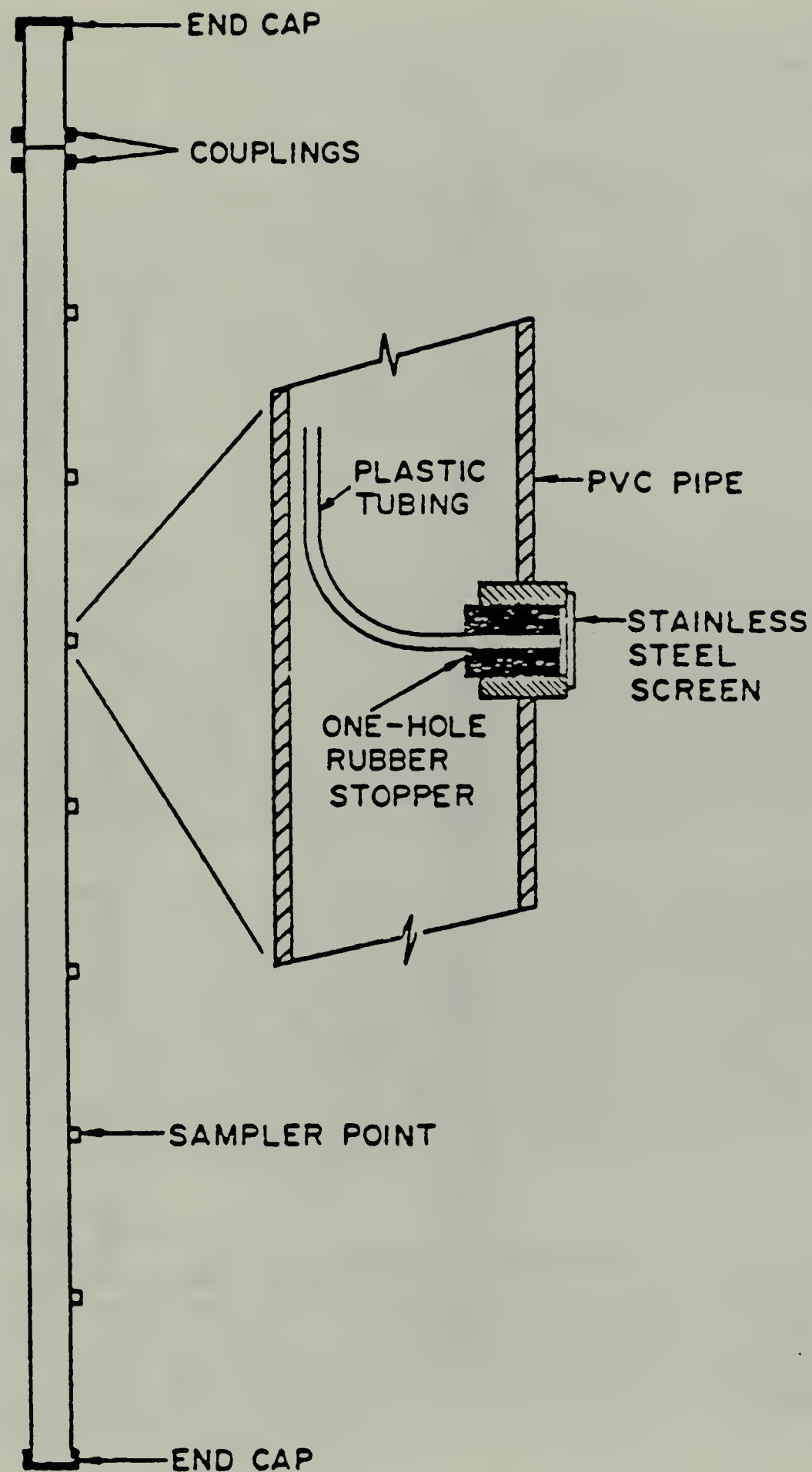


Figure 18. Suction-lift multilevel point sample (after Pickens et al, 1978).

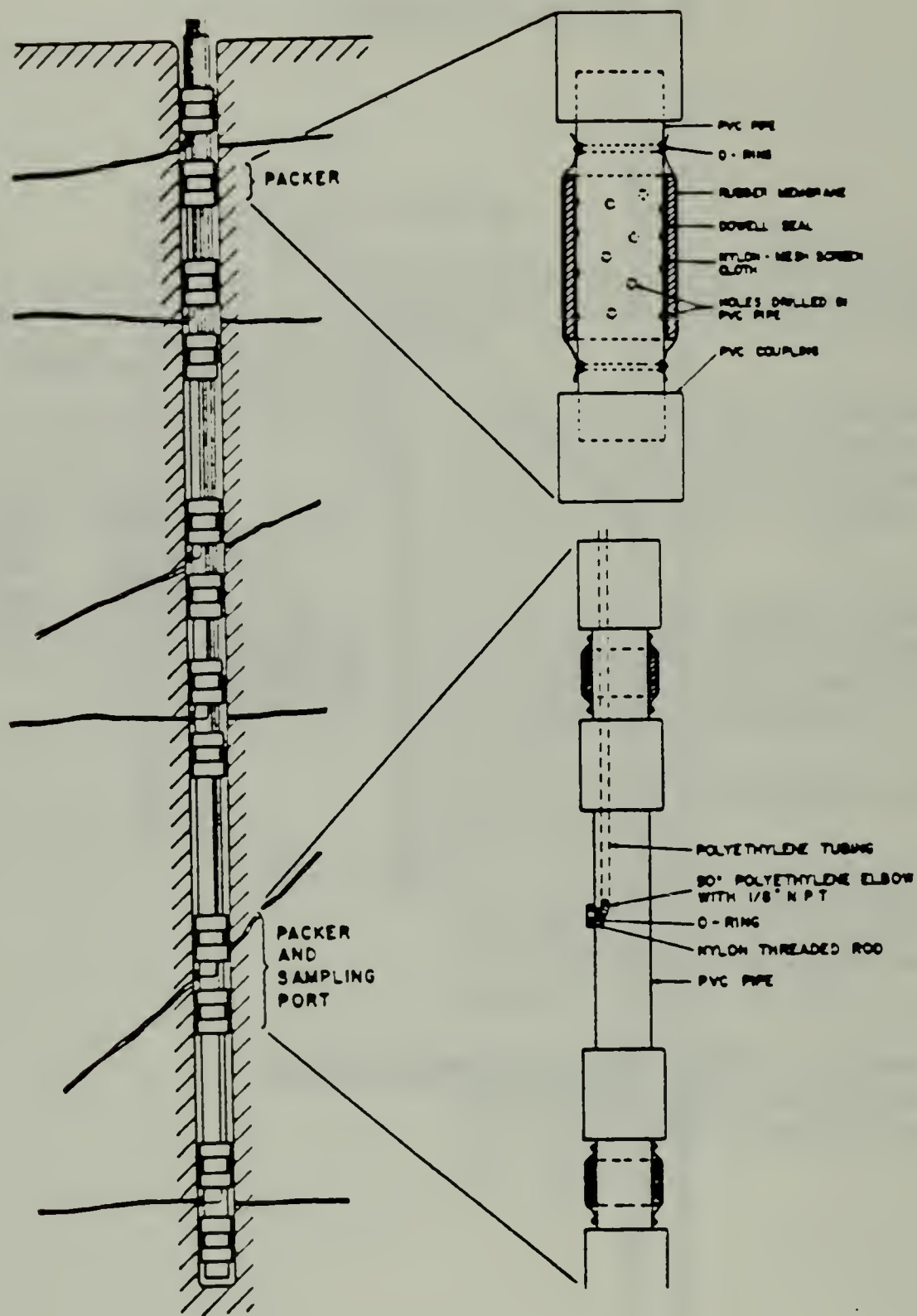


Figure 19. Schematic diagram of a six-port multi-level assembly and detailed views of a packer and sampling port system (after Gillham, 1983).

decisions regarding screen location, selection of materials, and modifications in construction or in the planned operation of the completed well. Split spoon sampling and water quality monitoring at discrete intervals should be standard protocol for the installation of all monitoring wells.

Common examples of quality related decisions include water zones to be excluded by casing or grouting; choice of casing and screen material; selective casing perforation; and screen placement. Electrical earth resistivity and electromagnetic conductivity surveys may provide information on areal extent of pollution at a reduced cost and within a short period of time. They can be most helpful in planning the test drilling and water sampling program. By eliminating hit-or-miss drilling, the number of wells needed will be considerably reduced.

Field Techniques for Locating Screens

One technique used to locate the number and depths of screens in a boring in situations involving volatile organic contamination is the use of a portable hydrocarbon analyzer. While advancing a boring, a portion of the split spoon sample is placed in a sealed jar and allowed to equilibrate to room temperature. The head space is then sampled for the amount of total volatile organics present. The detection limit for field units from different manufacturers varies from 0.2 ppb to 1 ppm. If soil samples are taken at discrete intervals (i.e. every five feet), then the vertical distribution of contamination (within the detection limits of the unit) can be assessed and the number and depth of screens determined.

This technique of monitoring a readily identifiable and quantifiable parameter while drilling is in progress can be used for other types of contamination as well. For example, specific conductance, chloride and pH can all be easily measured in the field. Thus, the field geologist not only knows the stratigraphy but also the degree of contamination as well and can better decide on the location and number of sampling points while the base-hole is still open. Once the well has been finished and allowed to equilibrate with its surroundings, samples should then be taken and sent to the laboratory for a more rigorous and comprehensive analysis.

Finishing Monitoring Wells

A typical monitoring well consists of a slotted or perforated section of pipe designed to allow the inflow of water while supporting the earth materials surrounding this screen. Attached to the screen is casing or riser pipe which extends above the soil surface. A guard pipe should be used that is equipped with a lockable and ventilated cap to prevent damage and vandalism to the well (Figure 20).

Observation and Monitoring Well Construction

1. Well Screen Packing

A well screen sand or gravel pack is recommended for wells located in unconsolidated materials of low permeability (10 slot/60 gauge or smaller).

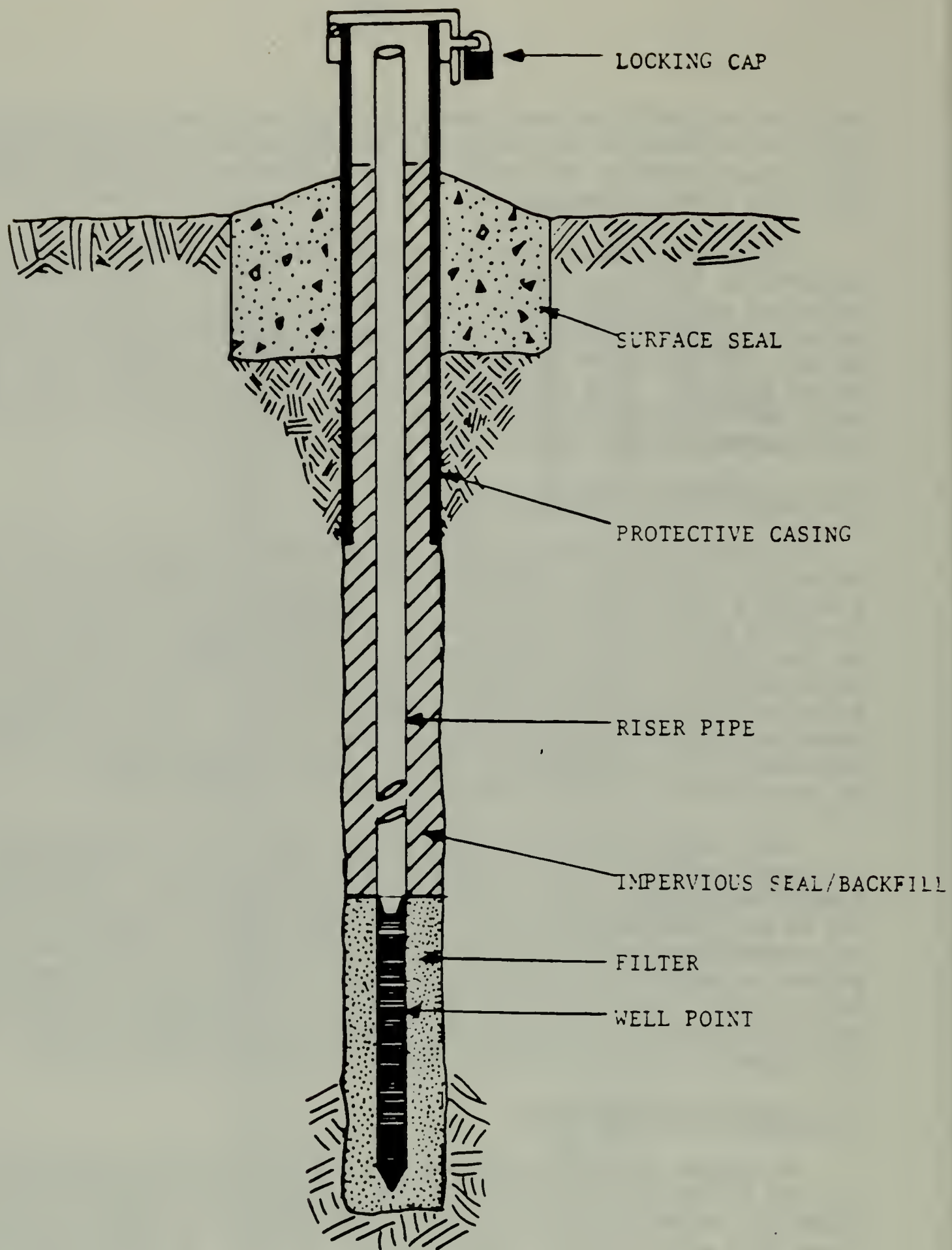


Figure 20. Construction of a finished monitoring well.

Screen openings should be selected based on the gravel pack grain size. Where a gravel or sand pack is considered to be desirable, the pack should be placed below and above the well screen for a distance of twelve inches or more. See Table 8 for advantages and disadvantages.

2. Grouting

The annular space between the casing and borehole should be sealed with an impervious material such as bentonite, native clay, or cement, or a mixture of these substances. Grout is used to: 1) protect the aquifer for the purpose of maintaining quality or preserving the hydraulic response of the producing zone; and 2) protect the entry of unwanted water into the aquifer from the surface or a subsurface zone.

To determine specific grouting requirements of a well at a designated site, consider:

1. Existing surface conditions - especially location of sources of pollution; and
2. Subsurface geologic and hydrogeologic conditions.

When sealing off a formation from undesirable water, the annular space should be grouted from at least 10 feet above to 10 feet below the water producing zone. See Table 8 for advantages and disadvantages.

3. Protection of Wells

At all times during the progress of the work the contractor should use reasonable precautions to prevent either tampering with the well or the entrance of foreign material into it. Metal casing should be cleaned before being lowered into a hole. Remove thread cuttings and oil with hexane or other suitable solvents. In addition, proper sealing of the annular area between the casing and the well bore is particularly important in preventing possible movement of contaminated water down the sides of the casing.

The casing should be securely capped with a locked vented cap. Caps should be vented in such a manner so as to prevent introduction of foreign materials through the vents.

Casing must also be protected against accidental damage. It should be marked adequately to be clearly visible during winter and summer conditions. Finally, all wells should be labelled and identified.

4. Documentation of Drilling Information

The driller and the supervising consultant must collect pertinent information regarding the stratigraphy, drilling method, soil sampling technique, depth of recovery, and installation of the monitoring wells. A form

Table 8. Advantages and disadvantages of common back-filling materials (after Gillham et al, 1983).

<u>POTENTIAL SOURCES OF BIAS</u>	<u>DIAGNOSTIC CONDITIONS AND/OR PRECAUTIONS</u>
<u>SAND PACK</u>	
-Contamination through contact with the formation water.	-Use inert materials such as silica sand.
	-Consider the packaging and handling of the sand to insure that it has not been contaminated.
	-Where there is reason for concern, the sand should be leached and the leachate analysed for the parameters of interest.
<u>CEMENT GROUT</u>	
-Installed as a slurry, therefore there is a significant potential for invasion of the formation and the sand pack.	-Unusually high pH values are generally indicative of contamination by cement grout.
-Exact boundaries of the seal are difficult to determine and to control.	-In multi-level installations, a change in water level in one piezometer caused by the removal of water from another, though inconclusive, is suggestive of a poor seal.
-Difficult to ascertain quality of seal.	
-Will contaminate the water in the immediate vicinity.	
-Heat of hydration can deform thermoplastics (eg PVC).	
<u>BENTONITE</u>	
-If installed as a slurry there is a significant potential for invasion of the formation and sand pack.	-Particulate bentonite or unusually high sodium concentrations in water samples are often indicative of bentonite contamination.
-Contamination can occur as a result of adsorption onto the bentonite or the release of cations from the bentonite.	-Increasing the length of the sand pack and, where possible, placing the bentonite as chips or pellets with the use of a tremie pipe will tend to reduce the contamination problems.
-Most bentonites contain a significant amount of organic matter (about 4 to 6%) and therefore can contribute organic constituents to the water.	-Bentonite expands upon wetting, therefore, if deposited in a dry condition, there is reasonable assurance of having a good seal after wetting.
-Pellets may "bridge" when installed, causing a leaky seal.	

is usually used which allows uniform data collection (Figure 21). A quick glance will show if any information has not been gathered or reported. In addition, a log of the general conditions at the monitoring site should be kept. This information includes weather, time of day, problems encountered and procedures used during the installation process. This documentation is very important so that, at a later time, problems involving sample validity can be minimized.

General Groundwater Monitoring Requirements

Appendix II, General Groundwater Monitoring Requirements, summarizes much of the above information. It reflects the minimum requirements established by the Department as specified in 310 CMR 30.00.

Monitoring Well and Test Hole Abandonment

Unsealed abandoned wells constitute a hazard to public health, safety, welfare, and to the preservation of the groundwater resource. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geological formations encountered, and the hydrologic conditions. To seal an abandoned water well properly, several tasks should be accomplished: (1) elimination of physical hazard; (2) prevention of groundwater contamination; (3) conservation of yield and maintenance of hydrostatic head of aquifers; and (4) prevention of the intermingling of desirable and undesirable waters.

The basic concept governing the proper sealing of abandoned wells is the restoration, as far as feasible, of the hydrogeologic conditions that existed before the well was drilled and constructed, for an improperly abandoned well might serve as an uncontrolled invasion point for contaminated and polluted water. Any well that is to be permanently abandoned should be completely filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently prevented, and the water is permanently confined to the specific zone in which it originally occurred.

To seal an abandoned well properly, the character of the groundwater must be considered. If the groundwater occurs under unconfined (water table) conditions, the chief problem is that of sealing the well with impermeable material so as to prevent the percolation of surface water through the original well opening, or along the outside of the casing, to the water table. If the groundwater occurs under confined or artesian conditions, the sealing operation must confine the water to the aquifer in which it occurs - thereby preventing loss of artesian pressure by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that in the aquifer which is to be sealed.

[illegible]

Figure 21. Soil sampling reporting form.

Water Sampling for Groundwater Monitoring

Flushing Monitoring Wells

Recent research into well-bore volume purging has cast suspicions on mandated removal of specified well volumes. Giddings (1983) explains "while this procedure is intended to improve the performance of the monitoring well and the sampling process, removal of several well-bore volumes of water prior to sampling collection often has exactly the opposite effect. Bailing is frequently used to remove the bore volumes of water and often induces turbidity in the sample which causes masking of parameters to be analyzed. Cascading of the water, refilling the purged bore, severely alters the levels of dissolved gasses and can cause significant changes in the aquifer quality." His major conclusion is that there is "no set number of well-bore volumes and no single sampling procedure that will work satisfactorily in all cases". The procedure for obtaining samples must be specific to the well design, aquifer characteristics, and parameters to be analyzed. Consistency in sample collection may be more important than the number of volumes removed.

Collecting Water Samples - (from Michigan Department of Natural Resources, Water Quality Division)

Sampling of monitor wells must be done in a way that minimizes or eliminates sample contact with the atmosphere. The method and type of equipment used to collect the water sample is a function of the parameters being sampled for. Components of sampling equipment must be considered when collecting a water sample just as the type of components are considered when constructing the well. When sampling for organic parameters, plastic (PVC) components of the sampler should be avoided. When sampling for metals, the metal components of the sampler must be non-reactive with the water being sampled. In all cases, construction components of the well and the sampling equipment must be inert to the water being sampled. Also, care must be taken during collection and handling to minimize the contact of the water sample with air. If sampling equipment is intended to be used on more than one well, all parts that contact the water should be conducive to easy and thorough cleaning.

Several methods of extracting water samples from monitor wells are discussed below. As with the construction of the sampling equipment, the nature of the sampling method may affect the quality of a water sample.

1. Bailers

This method of sample collection involves lowering a container (the bailer) down into the well until it fills with water. Once filled, the bailer is raised to the surface. Bailers are often constructed of either teflon, galvanized steel, or polyvinyl chloride (PVC); however, other materials may be used. The type of bailer used is determined by the nature of the chemical parameters suspected to be in the groundwater. If the suspected contaminant is organic in nature, a galvanized steel or teflon

bailer should be used rather than a PVC bailer because PVC tends to absorb organics. If metals are the suspected contaminant, a PVC bailer should be used rather than a steel or copper bailer, to ensure that metals are not added to the groundwater sample by the bailer.

Before collecting a groundwater sample, all standing water must be bailed from the well such that three to five complete volumes of water have been evacuated from the well. Depending on the initial volume of water in the well and on the depth to which the bailer must be lowered, bailing standing water may require a great deal of time and effort. If a large volume of water is needed for the sample, the bailer will have to be lowered and raised a number of times.

Use of the bailers may not be acceptable in all instances. Movement of the bailer in the well can cause turbulence of the well water. Agitation of the sample may cause loss of volatile components or precipitation of metals from the sample, thus resulting in a sample that is not representative of the groundwater aquifer.

2. Pitcher pump

A pitcher pump consists of a hand operated pump which pumps water to the surface by suction. The pump can be threaded directly on the casing of 1½ and 2 inch wells. For larger diameter wells, a drop pipe is attached to the pump and is placed down the well casing such that the end of the pipe is immersed in the water.

The pitcher pump is convenient to use and can pump relatively large volumes of water. However, it cannot pump water at depths greater than 25 feet. At these depths, suction cannot sufficiently be produced to pump water to the surface. Turbulence which occurs as the sample is collected may have an adverse effect on the water sample. Agitation of the sample can release volatile components and can cause precipitation of metals from the water resulting in a sample that is not representative of the aquifer being sampled. Uncontaminated water must be used for priming.

3. Air lift pump

In an air-lift pump, air is pumped down the well into the water through an air-lift pipe. As gas bubbles form in the water, the density of the water is reduced and water rises to the surface through the air-lift pipe.

A disadvantage of this method is that gases are introduced into the water sample. Addition of gases both agitates the sample and changes the chemical characteristics of the water. Agitation of the sample can result in the loss of volatile components from the sample. Addition of gases to the sample can alter the pH, carbonate, bicarbonate, organic and inorganic levels in the sample.

4. Shallow well centrifugal pump on suction pipe

In this method, a centrifugal pump is used to pump water from a well. A drop pipe (or suction pipe) is connected to the pump. The drop pipe is lowered into the well casing so that the lower end of the pipe is immersed in the well water. When the pump is started, suction is created in the drop pipe and water is drawn up through the pipe to the surface.

This method is easy to use and it is capable of pumping a fairly large volume of water. However, the method can only be used in relatively shallow wells as water cannot be lifted by suction more than 25 feet. Also, the suction may have an adverse effect on the quality of the water sample obtained. The suction may remove dissolved gases from the water sample, thus affecting pH and levels of other chemical parameters. Volatile components also may be lost from the sample due to suction.

5. Centrifugal-jet pump

This method is similar to the suction pump; but instead of just one pipe, two pipes are placed in the well. One of these pipes is fitted with a venturi foot valve. Water is pumped down this pipe. As water passes through the foot valve, it draws additional water from the well and the water is forced up the second pipe. More water is pumped up the second pipe than is pumped down the first pipe due to the intake of water by the venturi unit. Two pipes, however, are not always necessary. One pipe assembly is possible using the well casing as the second pipe.

A jet pump is capable of pumping 40 liters per minute and produces a continuous discharge of water. A disadvantage of the jet pump is that part of the water circulates back down the well and mixes with the sample water. The pump also requires priming so water used for priming must be uncontaminated.

6. Submersible pump

A submersible pump consists of a stack of impellers driven by a special motor designed for underwater use. The number of impellers stacked in the pump is determined by the distance the water needs to be lifted to the surface and by the amount of pressure required at the point of delivery. Each time water is pumped from one impeller to the next, its pressure is increased. The motor and pump assembly, which is built as one unit, is let down into the well on the end of a drop pipe to a position below the water table level. In this way, the pumping mechanism is always filled with water and ready to pump.

This type of pump can effectively be used in wells with large volumes of water, wells with great heads, and in deep wells.

Agitation of the sample, caused by the pump, can result in the loss of volatile components from the sample. There are two-inch submersible pumps now available that use a non-air-contact lift system that does not cause loss of volatile components due to agitation of the sample.

7. Tube pump

A peristaltic tube pump operates on a squeeze action principle. Successive waves of contractions force water through the tube to the surface. The water can then be used for sampling purposes. This type of pump is used in very specialized cases for wells at shallow depths and for sampling purposes only. It cannot pump large volumes of water and therefore cannot be used to purge or develop a well. See Table 9 and the supplemental tables in Appendix III for additional comments on sample collection methods and bias.

Prevention of Cross Contamination During Sampling

All sampling equipment must be thoroughly cleaned before being introduced into any well.

In the case of highly contaminated sites:

- a. Reusable sampling equipment should be assigned and used only at that particular site.
- b. Vehicles, clothing, gloves, etc., taken into a highly contaminated site, should be thoroughly cleaned prior to disposal or before use at a different site.

Monitoring Parameters

The parameters to be analyzed may vary considerably with each project depending upon the specific purpose or expected contaminants. Some parameters may be of general interest, particularly in preliminary investigatory work, as indicators of possible problems. Specific conductance, which measures the ability of water to carry an electric current due to ionized substances dissolved in the water, can be monitored to indicate the level of inorganic constituents. Measurement of the hydrogen ion activity expressed as a logarithm, pH, may be of general interest also. Both pH and specific conductance can be accurately performed on site with field portable instruments.

An indication of organic contamination can be found through the analyses of total organic carbon (TOC). Although higher levels of organic carbon may occur naturally in groundwaters, background levels are usually less than 2 mg/l. Higher levels of organic carbon generally indicate organic contamination, but the specific type of contaminants would have to be determined by more sophisticated analyses. Organic carbon analyses require the use of analyzers designed for this determination and would not generally be suited to field analyses. There are many kinds of organic carbon analyzers available from several manufacturers. Certain designs are more practical depending upon the particular applications intended. Some models are much more sensitive than others and may even be able to separately quantify volatile and non-volatile fractions. Sampling requirements may be instrument dependent. Nevertheless, the method employed to measure TOC must be capable of accurately measuring the volatile component or a volatile hydrocarbon scan must be included.

Table 9. Advantages and disadvantages of sample collection methods (after Gillham et al, 1983).

ADVANTAGES

DISADVANTAGES

DOWN-HOLE COLLECTION DEVICES (Figure 22)

General

- | | |
|--|---|
| <ul style="list-style-type: none"> -Greater potential to preserve sample integrity than many other methods because water is not driven by pressure differences. | <ul style="list-style-type: none"> -Most devices are unsuitable for flushing, because they provide only discrete, and often very small volumes of water. This problem can be avoided by using another method, which may be disruptive, to flush the installation, prior to using the down-hole collection device for sampling. |
|--|---|

Bailers

- | | |
|--|---|
| <ul style="list-style-type: none"> -Inexpensive to purchase or fabricate and economical to operate. This may permit the assignment of one collection device for each installation to be sampled, thereby circumventing problems of cross-contamination. -Very simple to operate, and require no special skill. -Easily cleaned, though cleaning of ropes and/or cables may be more difficult. -Can be made of inert materials. -Very portable, and require no power source. | <ul style="list-style-type: none"> -Usually very time consuming when used for flushing installations, especially when the device has to be lowered to great depths. It can also be very physically demanding on the operator when the device is lowered and raised by hand. -Can cause chemical alterations due to degassing, volatilization or atmospheric invasion when transferring the sample to the storage container. |
|--|---|

Mechanical Depth-Specific Samplers (Figure 23)

- | | |
|---|---|
| <ul style="list-style-type: none"> -Inexpensive to construct. -Very portable, and require no power source. -Stratified sampler is well suited for sampling distinct layers of immiscible fluids. -Can be made of inert materials. -Stratified sampler is easily cleaned. | <ul style="list-style-type: none"> -Some of the materials used can cause contamination (eg rubber stoppers). -Activating mechanism can be prone to malfunctions. -May be difficult to operate at great depths. -Can cause chemical alterations when transferring sample to storage container. -Difficult to transfer sample to storage container. -Kemmerer sampler is difficult to clean thoroughly. |
|---|---|

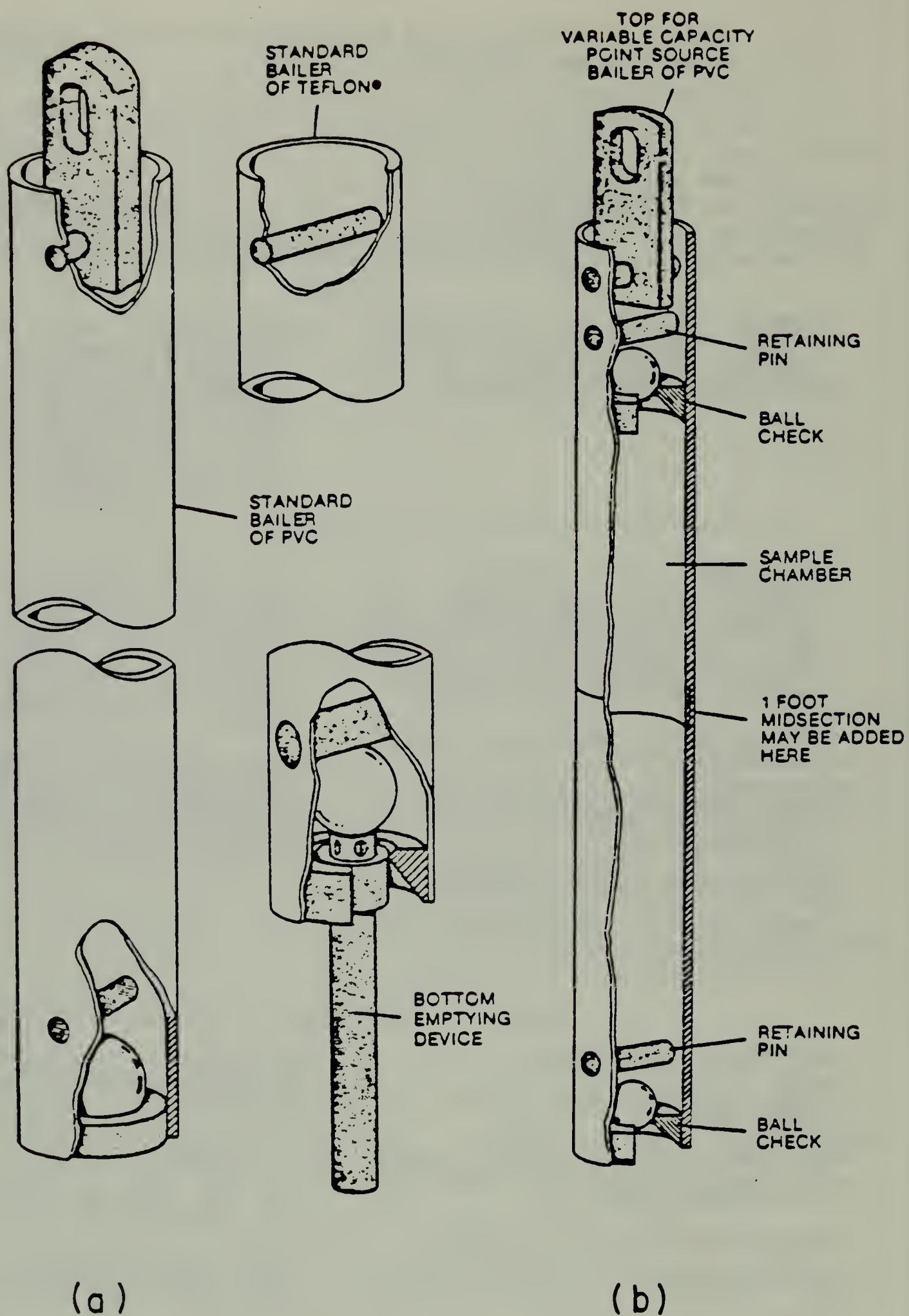
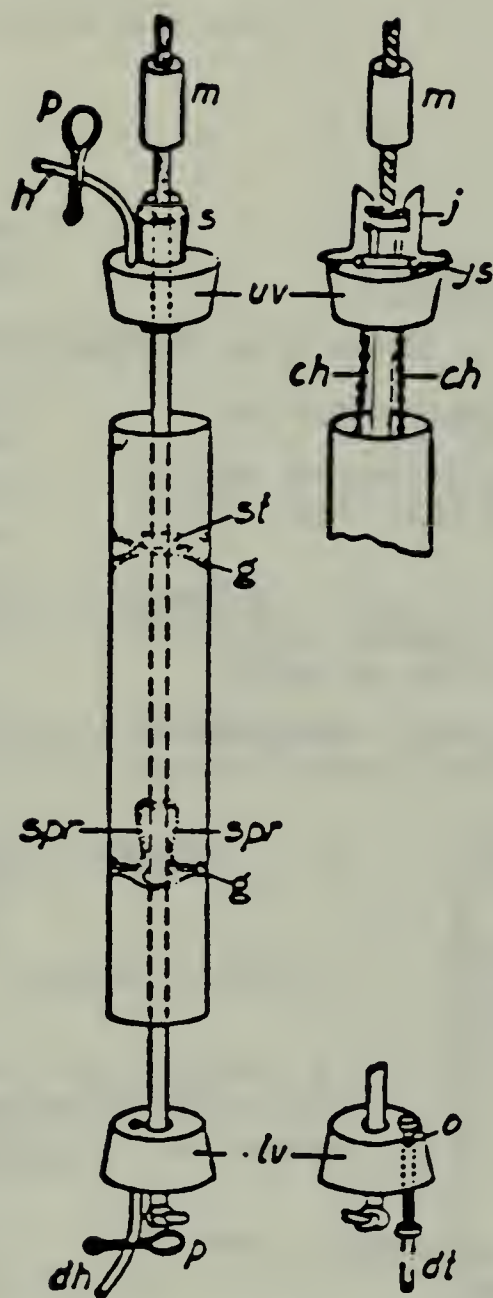


Figure 22. Bailers: a) standard type, and b) "point source" bailer. (Diagrams from Timco Mfg. Co., Inc., P.O. Box 35, Prairie du Sac, Wisconsin 53578).



- ch—chain which anchors upper valve to upper interior guide
- db—rubber drain tube.
- dt—brass drain tube
- g—interior guide fastened to inner surface of sampler.
- b—rubber tube.
- j—jaw of release.
- js—jaw spring.
- lv—lower valve.
- m—messenger.
- o—opening interior of drain tube.
- p—pinch cock.
- s—upper release spring operating on horizontal pin, one end of which fits into groove on central rod.
- spr—spring fastened to lower interior guide and operating in groove on central rod to provide lower release.
- st—stop on central rod
- uv—upper valve.

Figure 23. Depth specific bailer (Kemmerer Sampler) (after U.S. Environmental Protection Agency, 1977).

Table 9 (Continued)

ADVANTAGESDISADVANTAGES

Pneumatic Depth-Specific samplers (Figure 24)

- Can be made of inert materials.
- Easily portable, and require only a small power sources (eg hand-pump).
- Solinst sampler, and Syringe sampler can be flushed down-hole with the water to be sampled.
- Syringe of the syringe sampler can be used as a short term storage container.
- Syringe sampler is very inexpensive.

- Types that are commercially available are moderately expensive.
- Westbay sampler is only compatible with the Westbay casing system.
- Solinst, and Westbay samplers are difficult to clean.
- Materials used in disposable syringes of syringe samplers can contaminate the water.
- Water sample comes in contact with pressurizing gas in Solinst, and Westbay samplers (but not in syringe samplers).

SUCTION-LIFT METHODS (Figure 25)

- Simple, convenient to operate, and easily portable.
- Inexpensive to purchase, and to operate.
- Easily cleaned.
- Components can be of inert materials.
- Depending on the pumping mechanism, these methods can be very efficient for removing standing water from the sampling installations.
- Provide a continuous and variable flow-rate.

- Limited to situations where the water level is less than 7 - 8 m (23 - 26 feet) below ground surface.
- Can cause sample bias as a result of degassing and atmospheric contamination, especially if the sample is taken from an in-line vacuum flask.
- Can cause contamination if water is allowed to touch pump components.

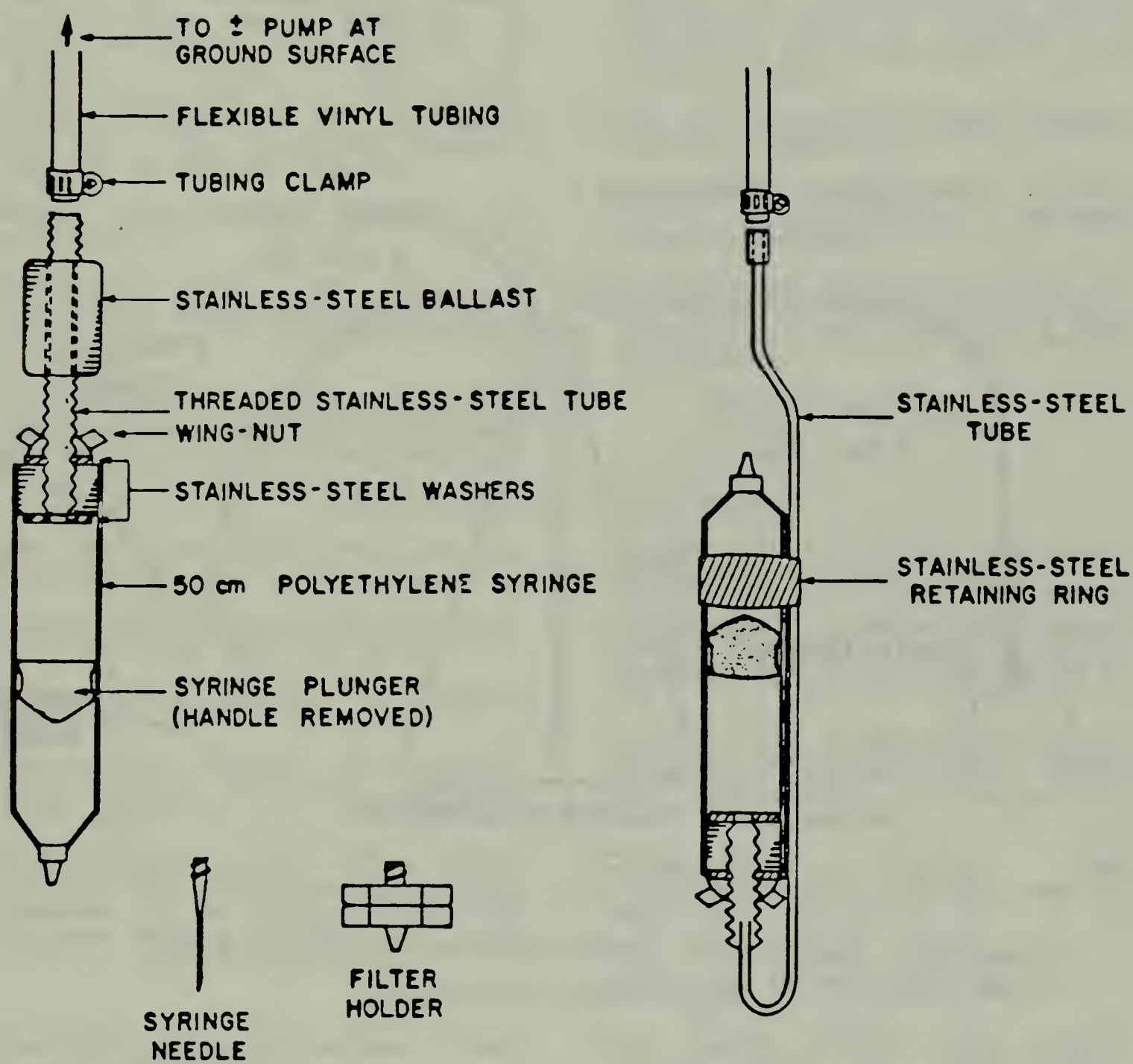


Figure 24. Syringe sampler (after Gillham, 1982).

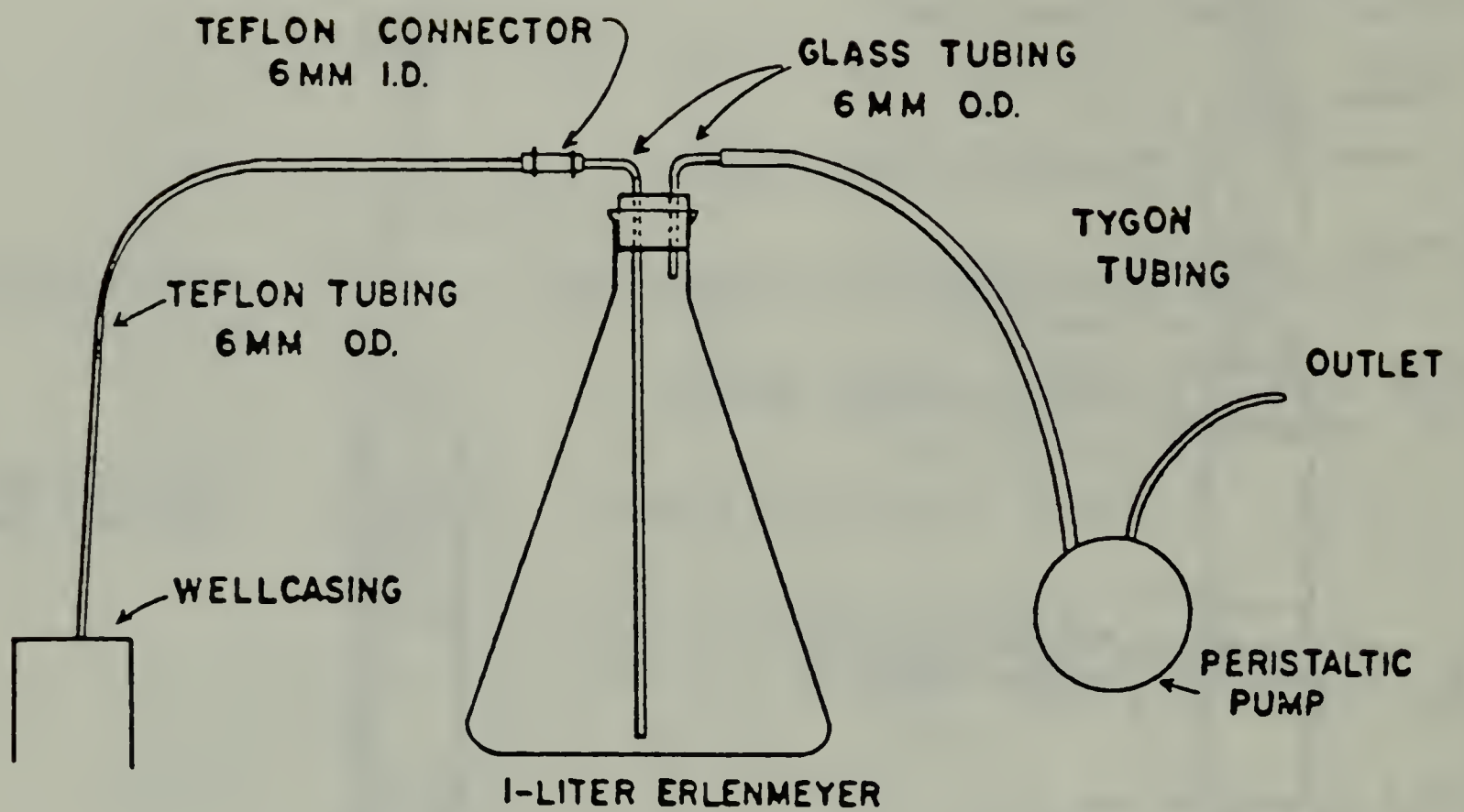


Figure 25. Suction-lift device with in-line suction flask (after Pettyjohn et al, 1981).

Table 9 (Continued)

ADVANTAGESDISADVANTAGESPOSITIVE-DISPLACEMENT METHODS

General

- Reduced possibility of degassing and volatilization because the sample is delivered to ground surface under positive pressure. In some situations, the pressure at ground surface may be substantially less than the natural water pressure in the formation and thus the degassing problem can not be entirely ignored.
- Sample does not contact the atmosphere.
- Sampling pumps for use in monitoring wells as small as 3.8 - 5 cm (1.5 - 2 in) are commercially available.
- Most of the commercially available devices have a sufficient flow rate for flushing sampling installations.

- Cost of the commercially available pumps is substantial (roughly \$2,000 to \$5,000). It would therefore not be feasible to dedicate a sampling pump to each sampling point.
- Can be difficult to clean between sampling sessions.
- Cleaning of cables and/or delivery tubing is required between sampling points.
- Commercially available devices are too large for very small-diameter installations such as the bundle piezometers.

Submersible Centrifugal Pumps

- Can pump at large and variable flow rates.
- Johnson-Keck pumps can fit down wells as small as 5 cm (2 in).
- Johnson-Keck pump is easily portable.
- Conventional pumps are usually much cheaper than the Johnson-Keck pump.
- Johnson-Keck pump offers little potential for sample contamination because it is made mostly of stainless steel and teflon.

- Subject to excessive wear in abrasive or corrosive waters.
- Conventional submersible pumps cannot be used in installations of diameter less than about 12 cm (4 in).
- Potential for contaminating water because of contact with metals and lubricants is larger in conventional pumps.
- Johnson-Keck pump has intermittent flow (15 min on, 15 min off).

Submersible Piston Pumps

- Gas-drive piston pumps have small power requirements.
- Gas-drive piston pump of Gillham and Johnson (1981) is inexpensive and can be assigned permanently to sampling point, thereby eliminating problems of cross-contamination.
- Double-acting pumps have continuous, adjustable flow rates.
- Can be built of inert materials (most commercially available pumps are not, however).

- Rod pumps require large power source, and are permanently mounted.
- Difficult to clean.
- When used as part of an installation the gas drive pump of Gillham and Johnson (1981) cannot be retrieved for servicing or repair.
- Single-acting pumps have intermittent flow.

Table 9 (Continued)

ADVANTAGESDISADVANTAGES

Gas-Squeeze Pump (Figure 26)

- | | |
|--|---|
| <ul style="list-style-type: none"> -Can be built of inert materials. -Comercially available pumps can fit in installations as small as 5 cm (2 in). -Can easily be taken apart for cleaning, but can be inconvenient to clean between sampling sessions. -Easily portable. -Good potential to preserve sample integrity because the driving-gas does not come in contact with the water sample. | <ul style="list-style-type: none"> -Intermittent but adjustable flow. -Require large but portable power source. |
|--|---|

GAS-LIFT METHODS (Figure 27)

- | | |
|--|---|
| <ul style="list-style-type: none"> -Simple to construct or are available commercially at relatively low cost. -Can be used in very narrow installations. -Can be easily portable. -Easily cleaned. | <ul style="list-style-type: none"> -Can only be used efficiently when roughly 1/3 of the underground portion of the device is submerged. -Contamination of the sample with the driving gas, atmospheric contamination and degassing are all unavoidable. -Need large power source (gas). |
|--|---|

GAS-DRIVE METHODS (Figure 28)

- | | |
|--|---|
| <ul style="list-style-type: none"> -Can offer good potential for preserving sample integrity, because very little of the driving gas comes in contact with the water sample, and because the sample is driven by a gradient of positive pressure. -Can be incorporated as part of the sampling installation, thereby removing the possibility of cross-contamination. -The triple-tube sampler is well suited for installations of very narrow diameter e.g. 0.95 cm (3/8 in) where the only other possible sampling method is narrow-tube bailers, or suction-lift (when applicable). -Inert materials can be used. | <ul style="list-style-type: none"> -Not very efficient for flushing installations larger than about 2.5 cm (1 in). -Can be difficult to clean between sampling sessions. -The driving gas comes in contact with the water, and therefore the beginning and the end of the slug of water obtained at the surface can be contaminated. -When used as part of a permanent sampling installation, they cannot be retrieved for repair or servicing. -Pump intermittently, and at a variable flow-rate. |
|--|---|

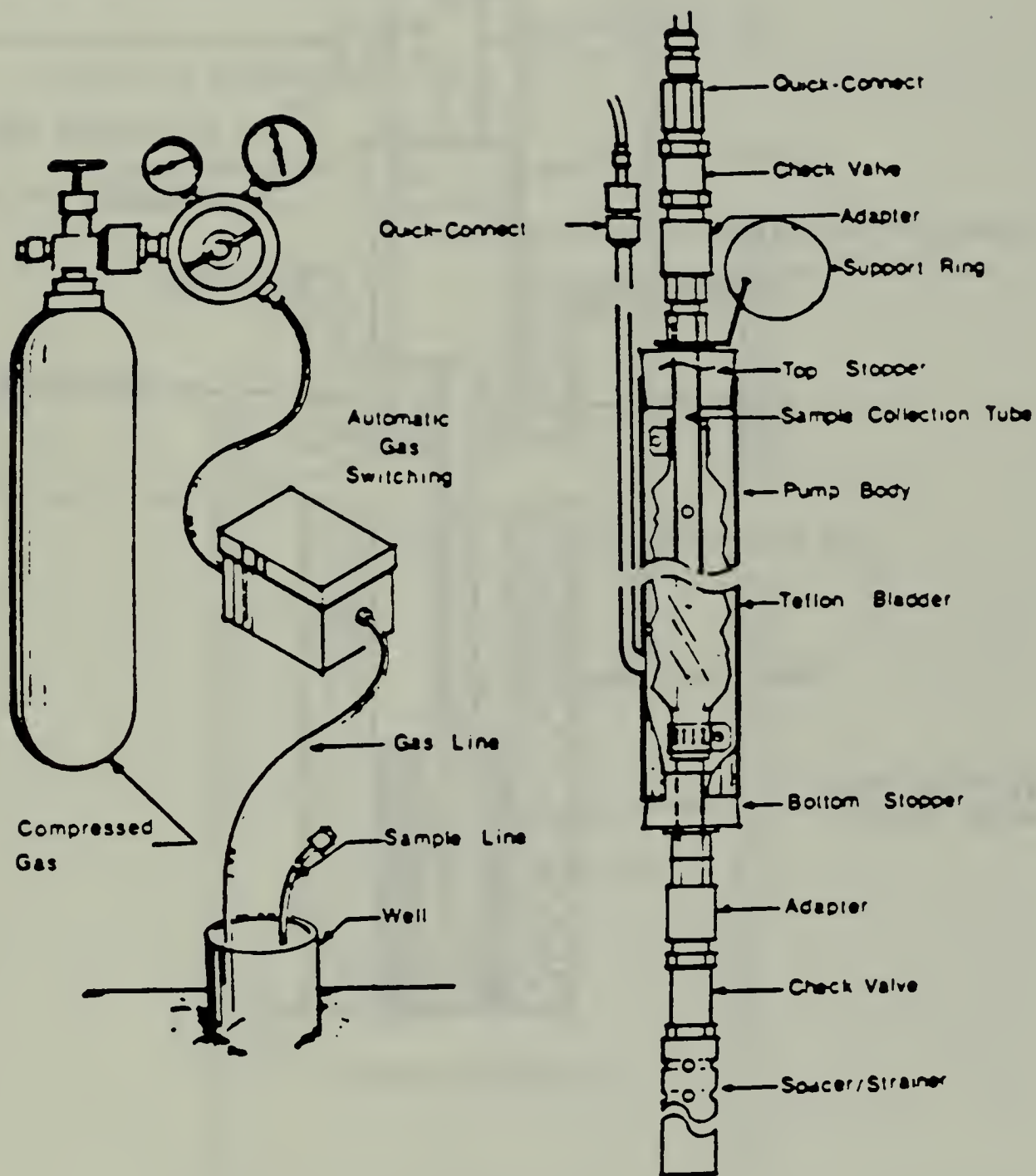


Figure 26. All teflon, and stainless-steel bladder or squeeze pump (after Unwin, 1982).

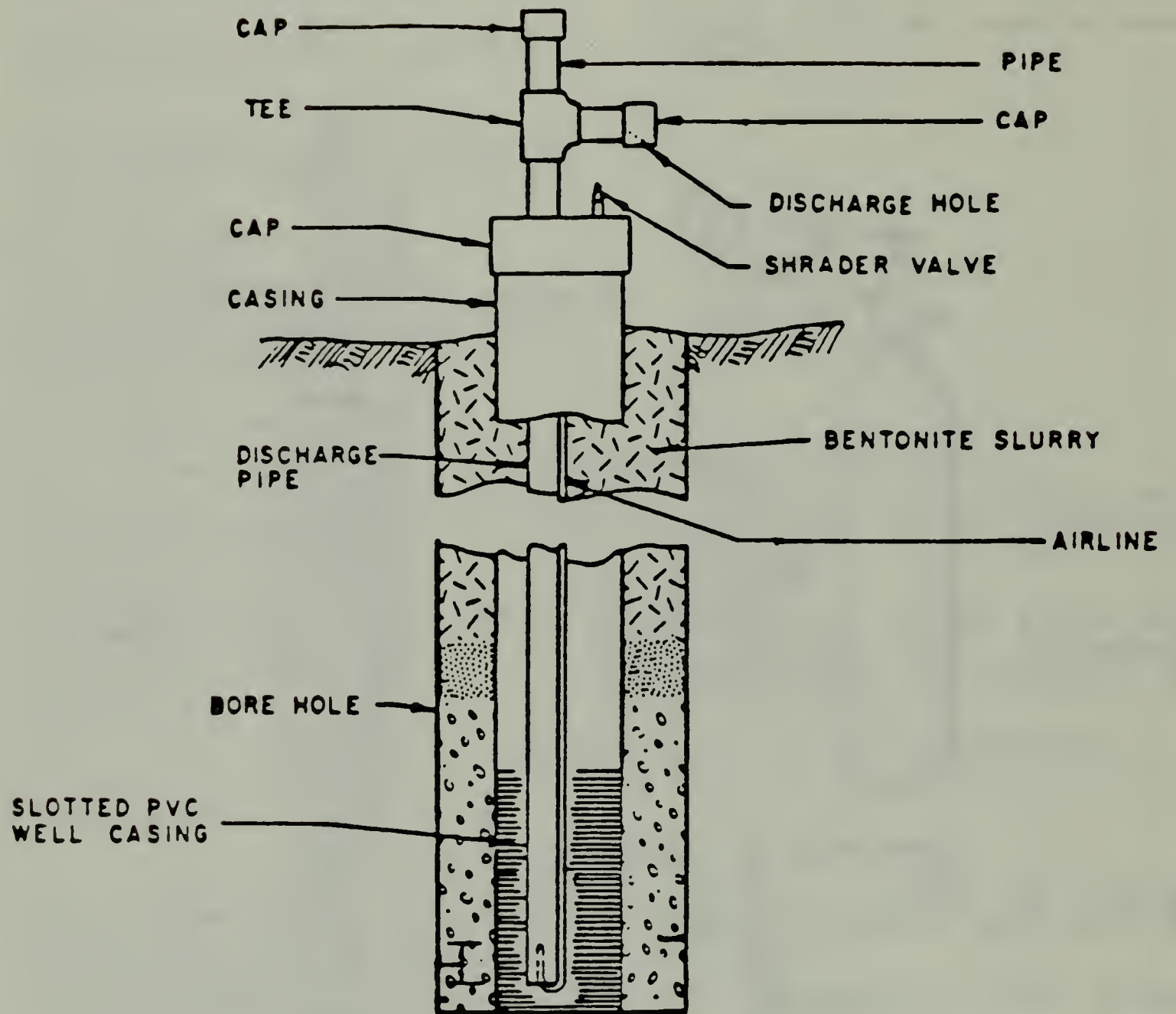


Figure 27. Gas-lift sampler (after Walker, 1974).

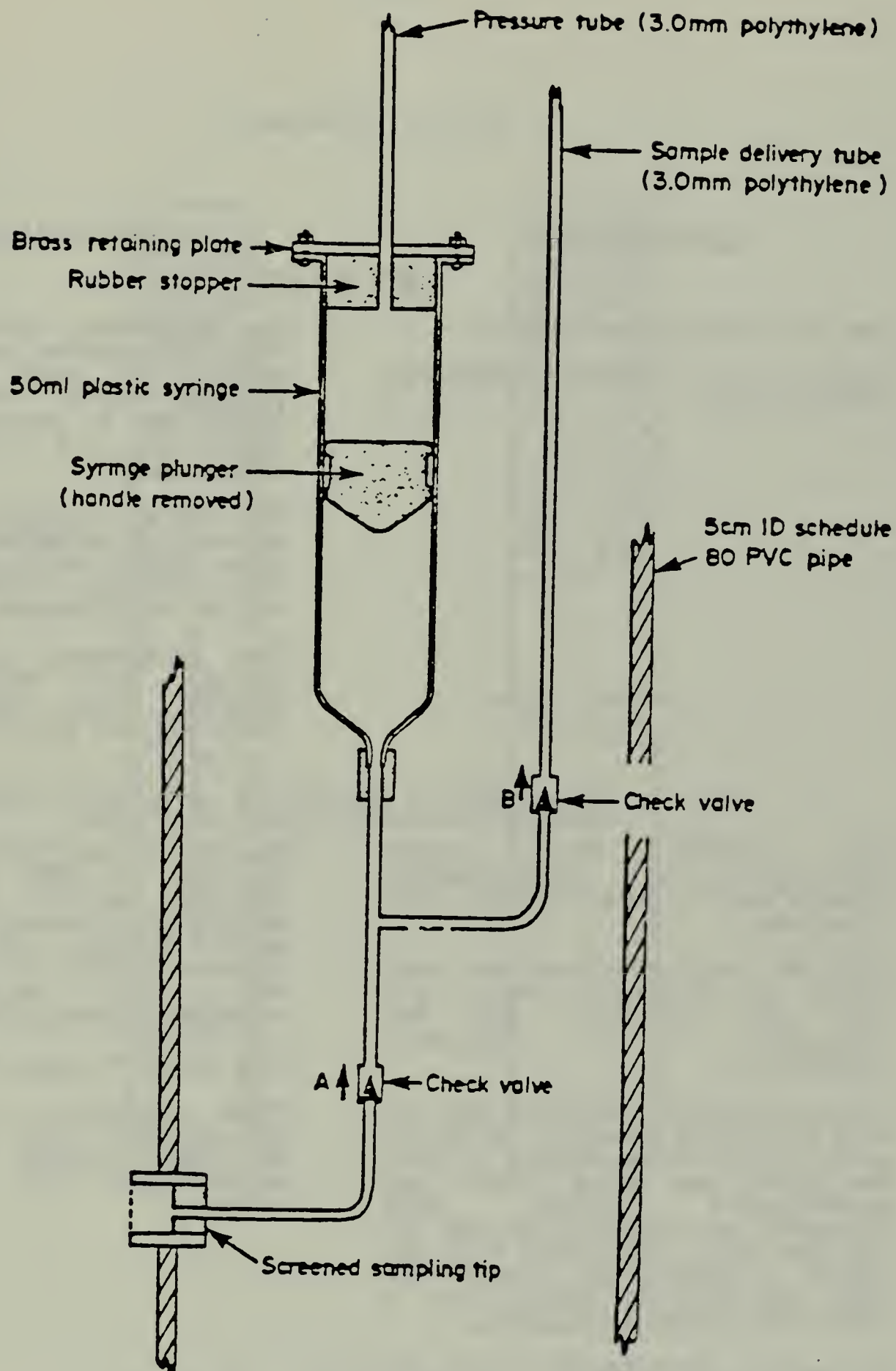


Figure 28. Positive displacement pump: single acting gas-driven piston pump (after Gillham and Johnson, 1981).

Table 9 (Continued)

<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
<u>JET-PUMPS</u>	
-Can be used at great depths.	-Use circulating water which mixes with the pumped water. A large amount of water needs to be pumped before the circulating water has a composition that is close to the water in the installation.
-Useful for flushing monitoring installations.	-The water entering the venturi assembly is subjected to a pressure drop (which may be large), and can therefore undergo degassing and/or volatilization.
	-The circulating pump at the surface can contaminate the pumped water because of its materials and lubricants.

*

DESTRUCTIVE SAMPLING METHODS (Figure 29)

- Can provide very useful information in reconnaissance surveys and in other specific field situations.
- Most of the techniques are used during the drilling operation and will not interfere with the implantation of a permanent installation.
- Coring-extraction methods are the only convenient means of obtaining several parameters related to both the liquid and solid phases (eg. exchangeable cations, total microbial population, samples of the formation, etc.), and also, for certain situations they may be the least bias-inducing method (eg. in very fine-grained formations).
- Temporary installations can, in some situations, be the most cost-effective way of obtaining preliminary, and/or reconnaissance data.
- Because no permanent installation is left in the ground, these methods cannot be used for monitoring long-term trends in water quality. In most cases, however, they do not interfere with the implantation of permanent installations.
- Can result in large drilling costs.
- Water contained in cores can be contaminated with drilling fluids and can undergo degassing and volatilization at the ground surface.

*

Destructive groundwater-sampling methods represent a group of methods, or an approach, quite apart from those described previously in this handbook. The principal difference between these and the more conventional approaches to sampling is that no permanent installation is left in the ground. As a result, they are generally not suitable for long-term monitoring at waste-management sites but may be applicable in reconnaissance surveys or in other specialized site-specific situations. For further discussion see Groundwater Monitoring and Sample Bias (Gillham et al, 1983).

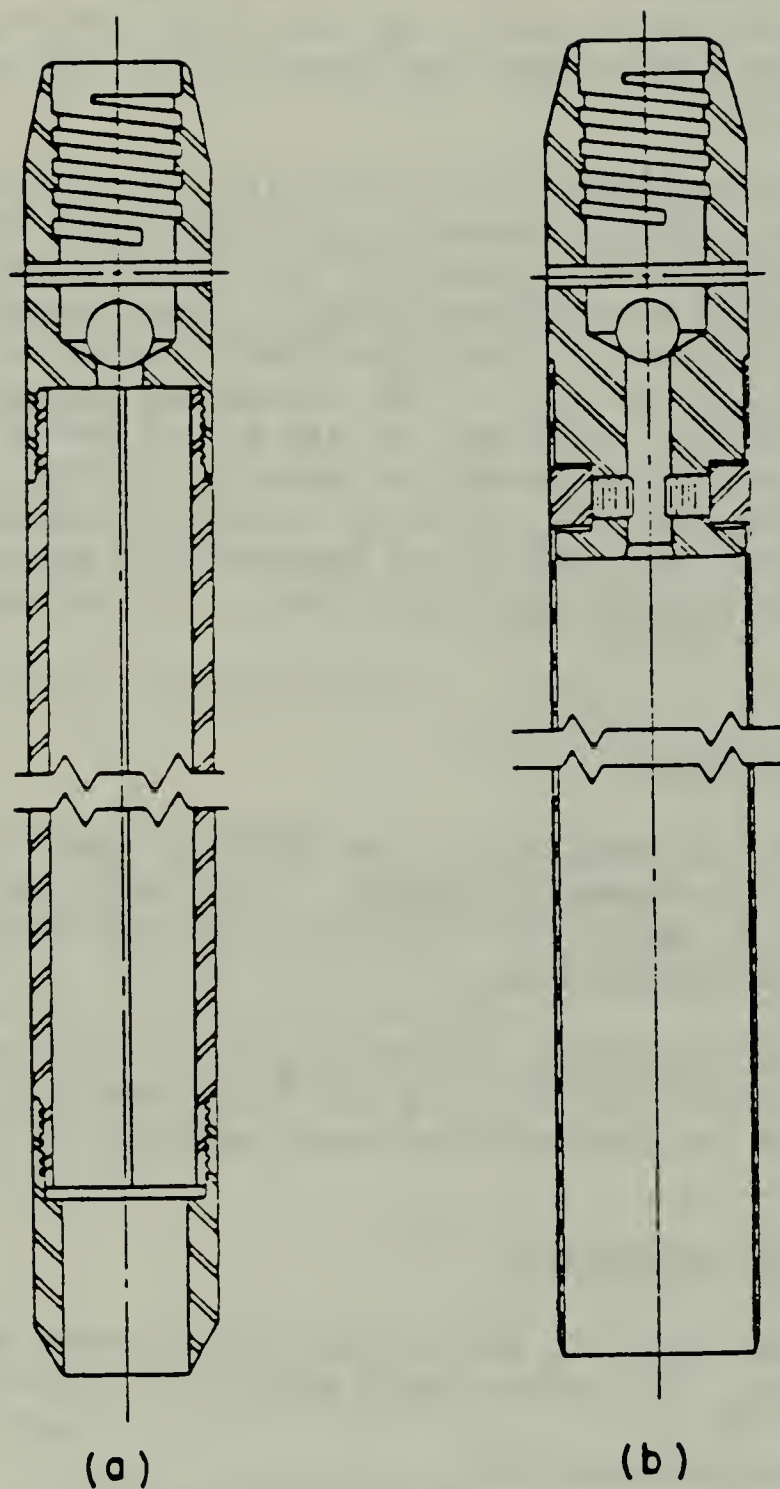


Figure 29. Destructive sampling methods: a) split-spoon sampler, b) thin-wall shelly tube. (Diagrams from J. K. Smit and Sons, Ltd., 17222 South Golden Rd., Golden, Colorado 80401).

Chemical oxygen demand (COD), although less sensitive than TOC and less specific to organic constituents, may be useful as an indication of gross organic contamination. The main advantage to COD analyses is the use of more common laboratory apparatus. For many samples, the COD is approximately three times higher than the corresponding TOC due to the difference in reporting units.

If inorganic contamination is indicated or suspected, analyses for the common anions and cations should be performed along with probable less common ions. An ion balance analysis of the results (where the cations and anions are converted to milliequivalents, summed separately, and compared) should indicate whether all the major ions present have been measured for possible gross inaccuracies. If all parameters have been analyzed for dissolved constituents, agreement of the cation and anion sums is usually within 5%. The essential anions are usually chloride, sulfate and bicarbonate. Carbonate, nitrate, nitrite, silicate, bromide, fluoride, phosphate, sulfide, and sulfite are necessary on some samples. The necessary cations usually consist of iron, calcium, magnesium, sodium, and potassium.

Frequency of Sampling

The frequency of sampling by the owner or operator should be designated and approved by the requesting agency. This sampling frequency should be sensitive enough to detect the impacts on or significant changes from outside of the contaminated areas.

Determine the frequency of sampling by a) rate of groundwater flow, b) potential of affecting existing and future water supplies, and c) chemical composition and characteristics of possible contaminants.

Reporting of Sampling Results

A groundwater sampling and analysis plan should be developed for all sampling programs. This plan should state the following procedures and techniques:

- a) Date and place of sample collection;
- b) A quality assurance plan for sample collection (this should include a discussion of sampling methods, treatment preservation, storage and shipment);
- c) A quality assurance/quality control plan for laboratory analysis, including analytical procedures and detection limits, and units of measurement;
- d) Chain of custody control (see Figure 30).

CHAIN OF CUSTODY RECORD

1. Sample Collection

I _____ collected _____ samples
Name No.
marked _____ from _____
Sample identification letter and/or No. City or Town

Source Station or Location
on _____ at _____
Date Time
Signature of Person Taking Sample(s) _____

Agency
Signature of Witness to Taking Sample(s) _____

Agency

2. Sample Transportation and Delivery

I _____ transported and delivered _____ samples
Name No.
marked _____ and collected from _____
Sample identification letter and/or No. City or Town
to _____ on _____ at _____
Place of Delivery Date Time
Signature of Person Transporting and
Delivering Sample(s) _____
_____ Agency

3. Sample Recipient

I _____ received _____ samples
Name No.
marked _____ and subsequently numbered _____
Sample identification letter and/or No.
_____ from _____
Laboratory Number(s) City or Town
_____ Source Station or Location
from _____ on _____ at _____
Name of Person Delivering Sample(s) Date Time
Signature of Person Receiving Sample(s) _____
_____ Agency

Figure 30. Chain of custody record.

Laboratory Methods

Standardized approved analytical laboratory methods must be used to insure the validity and comparability of analytical results. Any questions regarding laboratory methods or laboratory certification should be directed to the Lawrence Experiment Station. The U.S. Environmental Protection Agency has prepared lists of approved test procedures for the analysis of certain environmental pollutants (e.g., 40 CFR Part 136). The most recent lists are pending review and approval, but can be found in the "Federal Register", Vol. 44, No. 233, December 3, 1979, pp. 69464-69475 and Vol. 44, No. 244, December 18, 1979, pp. 75028-75049. If more than one approved method of analysis is listed, the most applicable method should be employed depending upon the sensitivity required, potential interferences, and other factors.

Occasionally, the use of methods not on the list of approved methods is desired due to expertise with alternate procedures or lack of the necessary equipment, laboratory supplies, or trained personnel to perform the approved method. Alternate test procedure approval should be obtained from the Lawrence Experiment Station before an unapproved method is employed. The proposed method of analysis should demonstrate equivalency to an approved method and have precision and accuracy sufficient to perform the desired analyses.

Preservation Methods and Holding Time

Many parameters are significantly labile and require special chemical or physical preservation techniques, collection in specific sample containers, and analysis within a certain period of time. "Table II. Containers, Preservation, and Holding Time" (Federal Register, Vol. 44, No. 244, December 18, 1979, pp. 75050-52) lists proposed sample containers, preservation techniques, and maximum holding times for 228 environmental parameters.

Quality Control

Careful attention should be paid to the many aspects of sample collection, preservation, handling, and analysis to insure the generation of valid data. Quality control functions are those specific aspects of a project which are designed to insure and monitor the quality of the results. Quality control procedures may not necessarily improve the quality of results, but should define how reliable they are. If the problems noted by quality control audits are properly interpreted and corrected, the validity of analytical results will improve. Quality control audits are generally a combination of field and laboratory checks. The Handbook for Analytical Quality Control in Water and Wastewater, March 1979, EPA-600/4-79-019, is a useful reference for establishing quality control procedures and evaluating their results. As a minimum effort, a quality control program may include:

1. Approximately one in twenty-five samples collected in duplicate as a check on sampling techniques and the ability to collect a representative sample;

2. A set of field blanks with each batch of samples to check container suitability and the purity of preservatives;
3. Replicate sample analysis with each analytical batch to check and document the precision of analytical methods;
4. Spiked sample analysis with each analytical batch to audit and evaluate analytical accuracy; and
5. Use of statistically derived control limits to indicate when an out-of-control situation exists and analyses must be repeated.

Soil Sampling Procedures

This section contains recommended procedures for collecting, handling and analyzing soil samples as part of a hydrogeologic study program and is taken from the Michigan Department of Natural Resources, Water Quality Division, "Hydrogeologic Study Handbook", March 1982.

Collecting Soil Samples

Soil samples suitable for field investigation and laboratory characterization should be collected whenever possible during the drilling of boreholes by either coring, split-spoon, or shelby tube sampling at regular intervals. In general, samples collected from solid stem auger flights and screened from circulating drilling mud would not provide sufficient accuracy for soil characterization studies.

Field Handling of Samples

Where necessary, special field handling procedures are to be implemented to insure that the collected soil sample does not alter in character prior to analysis. The recommended procedure for undisturbed soil samples is the sealing of the sample in the shelby tube sampler for transportation to the laboratory. For disturbed soil samples, suitable storage procedures should be followed to minimize soil moisture losses and air contact.

1. Extracting and Storing Soil Water

It is recommended that separation of the soil water for analysis be done in the field whenever possible.

2. Storing Soil Samples

For prolonged storage of soil samples in the shelby tube it is recommended that plastic or aluminum samplers be used. If hydrocarbon analysis is to be done, however, plastic samplers should not be used.

The storage environment for soil samples in the laboratory should simulate the subsurface environment. Recommended environmental conditions

are the absence of light, sealing to prevent contact with air, and a storage temperature from 4° to 7°C. Soil samples should not be frozen.

3. Analyzing Soil Water

Analysis of soil water pH, Eh, and temperature should be done in the field. Subsequent soil water analysis in the laboratory should include pH, heavy metal content, alkalinity, sodium, sulfate, chloride, calcium, magnesium, total nitrogen, total organic carbon, and any other specific parameters of interest.

Analyzing Soil Samples

1. Field Analysis

In addition to borehole formation, sample logging, or visual examination of the soil sample characteristics, it is recommended that the analysis of soil pH and temperature be done in the field.

2. Undisturbed Soil Laboratory Analysis

Depending upon the type of contamination, the laboratory analysis of undisturbed soil samples should include permeability, cation exchange capacity, organic content, resident exchangeable ions, sieve and hydrometer analysis, clay mineralogy, bulk density, moisture content, and specific gravity.

3. Field Permeability Testing

Knowing the hydraulic conductivity (coefficient of permeability) is important because, coupled with the saturated thickness and piezometric surface of the aquifer, an estimation of the amount of groundwater moving through a contaminated site can be determined. Also, an initial estimate of the groundwater flow velocity and thus migration distances of contaminants can be made.

The preferred approach to estimating hydraulic conductivity is field testing by either slug tests or pump tests. Field testing of in situ soil permeability generally results in a more representative value of hydraulic conductivity when compared to values obtained from laboratory analyses.

Sampling Statistics

1. Sampling Techniques (Strategies)

The objective of a sample survey is to make inferences about the "population" or entire group based upon information contained in a sample or part of the group. In the sampling of groundwater, a water quality sample taken from a well is extrapolated to include the entire aquifer or

area of concern. Besides the technical problems associated with the drilling of wells and extracting volumes of water for analysis, the number of wells and timing of sampling is very important. Thus, a simple discussion of sampling strategies will present the basic information necessary to design a groundwater monitoring program that will yield statistically significant information about the study area.

2. Simple Random Sampling

This technique requires selecting n units out of a population of size N in such a way that each unit of the population has an equal chance of being selected. This technique should not be confused with haphazard sampling (experimenter uses own judgement to "randomly" select samples) or representative sampling (experimenter chooses a sample considered to be typical or representative of the population). Both haphazard and representative sampling are biased by the judgement of the experimenter. The results of these techniques can not be used in statistical analysis. Simple random samples can be selected by using tables of random numbers, found in most statistics books.

In groundwater monitoring, if samples are extracted from existing wells, these wells can be considered a subpopulation of all possible locations in the aquifer. Simple random samples taken from these wells ensure that a bias or correlation will not be introduced. In groundwater monitoring, the definition of the population will vary by monitoring objective. If the monitoring system is designed to determine the quality of drinking water, then the population consists of all the drinking water wells in the aquifer. If the objective is background groundwater quality, then all possible locations within the aquifer is the population (Nelson and Ward, 1981). "In this case, inferences made from existing wells strictly apply to that subpopulation only. Extrapolation of such inferences to the entire basin requires the additional assumption that wells are located randomly throughout the basin."

3. Systematic Sampling

Systematic sampling is achieved by randomly selecting one element from the first K elements and then selection of every K th element thereafter. For groundwater monitoring, systematic sampling is appropriate for sampling in time. Thus, one sample would be chosen and an additional sample taken every hour, day, month, etc..

Mendenhall et al (1971) state that systematic sampling is preferable to simple random sampling because of the following:

- a. "Systematic sampling is easier to perform and hence is less subject to interviewer errors than simple random sampling.

- b. Systematic sampling often provides greater information per unit cost than does simple random sampling."

To draw a systematic sample, the first sample is chosen by using a table of random numbers and then every Kth element is selected until the required sample size is chosen.

One problem associated with systematic sampling is drawing samples from populations with cyclic variations. The results of the sample design may not be representative of the overall population.

4. Stratified Random Sampling

"A stratified random sample is obtained by separating the population elements in nonoverlapping groups, called stratum" (Mendenhall et al, 1971). The major factors supporting the use of stratified random sampling are:

- a. Data within each strata should be more homogeneous than the total population.
- b. The cost of conducting this type of sampling strategy is usually less than simple random sampling.
- c. Separate estimates of population parameters can be obtained for each stratum without additional sampling.

To draw a stratified random sample, the population is divided into appropriate strata and then samples are selected using the simple random sampling procedures. For groundwater studies, the population can be stratified by area, depth, time, etc..

Comparison of the above mentioned sampling techniques (simple random sampling, systematic sampling, stratified random sampling) reveals that the "variance for either systematic or stratified random sampling will be smaller than the variance for simple random sampling" (Nelson and Ward, 1981).

The purpose of this discussion of sampling strategies was to present the basic principles of sampling theory to avoid the collection of inefficient, unreliable and costly groundwater data. Careful planning in the design of groundwater monitoring systems will result in the collection of reliable and cost-effective data.

This should not be interpreted to mean that if samples are selected according to the reviewed sampling strategies that the results will be error-less. Haan (1977) states that "the quality of any statistical analysis is no better than the quality of the data used - it can be worse, but no better." Statistics is a tool to aid in the understanding of a population. Professional judgement and careful planning are prerequisites to a well designed groundwater monitoring program.

APPENDIX I

CHEMICAL RESISTANCE OF PIPING MATERIALS

Table A I-1. Chemical resistance of piping materials. R = Recommended
NR = Not Recommended
• = No Data

ION, SUITE B-5
ENGLEWOOD, COLORADO 80110

CHEMICAL <small>See Remarks On Page</small>	PVC		CPVC			PENTON				POLY ETHYL ENE		POLYPROPYLENE				KYNAR			FIBERGLASS REINFORCED EPOXY				FIBERGLASS REINFORCED POLYESTER				FIBERGLASS REINFORCED VINYLESTER				VITON				
	70	140	70	140	185	80	150	220	250	70	120	70	120	150	180	70	150	250	70	150	225	250	70	120	150	250	70	100	150	200	70	185			
Acetaldehyde	NR	NR	.	.	.	R	R	NR	NR	R	NR	R	R	.	.	.	.	.	NR	NR	NR	.	.	.	.	.	.	.	.	.	NR	NR		
Acetic Acid	R	R	R	R	.	R	R	R	R	R	R	R	R	R	R	.	.	.	R	R	R	.	R	R	R	R	R	R	R	R	R	R			
Acetic Acid 10%	R	R	R	R	NR	R	R	R	R	R	R	R	R	R	R	.	.	.	R	R	.	.	R	R	R	R	R	R	R	R	R	R			
Acetic Acid 20%	R	R	R	R	.	R	R	R	R	R	R	R	R	R	R	.	.	NR	R	.	.	.	R	R	R	.	R	R	R	.	R	R			
Acetic Acid 50%	R	R	.	.	NR	R	R	R	R	R	R	R	R	R	R	.	.	.	R	NR	NR	NR	R	R	R	.	R	R	R	.	R	R			
Acetic Acid 80%	R	NR	NR	NR	NR	R	R	R	R	R	R	R	R	NR	NR	R	R	NR	R	R	NR	NR	NR	R	R	.	.	.	.	.	NR	NR		
Acetic Acid Glacial	NR	NR	NR	NR	NR	NR	NR	.	.	R	R	R	.	.	.	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	.	NR	NR	
Acetic Anhydride	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	NR	NR	NR	NR	NR	NR	R	NR	NR	NR	R	R	R	NR	R	R	NR	NR	NR	NR			
Acetone	NR	NR	.	.	.	.	.	.	.	.	.	R	R	.	.	R	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Acetophenone	.	.	.	.	.	NR	NR	NR	NR	.	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R
Acetyl Chloride	R	R	R	R	.	NR	NR	.	.	NR	NR	R	.	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R
Acetylene	NR	NR	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	R	.	.	.	.	.	.	.	.	NR	NR	NR	NR	.	.	
Acrylic Acid Ethyl Ester	.	.	.	.	.	R	R	.	.	.	.	.	.	.	.	R	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	NR	NR
Acrylonitrile	R	R	R	R	R	R	R	R	R	R	.	R	.	.	.	R	NR	NR	R	R	R	.	R	R	R	.	R	R	R	R	R	.	.		
Adipic 10% Acid	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R	R
Alcohol Allyl	R	NR	.	.	.	R	R	R	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R		
Alcohol Amyl	R	NR	R	R	NR	R	R	R	.	R	R	R	R	R	R	R	R	R	R	NR	NR	NR	NR	R	R	R	R	R	R	R	R	R	R		
Alcohol Benzyl	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	NR	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	R	R
Alcohol Butyl Primary	R	R	R	R	R	R	R	R	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	R	R
Alcohol Butyl Secondary	R	R	R	R	NR	R	R	R	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	R	R
Alcohol Diethylene	.	.	.	.	.	.	.	.	.	NR	NR	R	NR	NR	NR	R	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	NR	NR
Alcohol Ethyl	R	R	R	R	R	R	R	R	NR	NR	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R		
Alcohol Methyl	R	R	.	.	.	R	R	R	.	R	R	R	R	R	R	.	.	.	R	R	R	R
Alcohol Isobutyl	R	R	R	R	R	R	R	R	NR	R	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	NR	NR
Alcohol Methyl	R	R	R	R	R	R	R	R	NR	R	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.
Alcohol Propyl	R	R	R	R	NR	R	R	R	R	R	R	NR	NR	NR	NR	NR	R	NR	NR	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	R	R
Alcohol Propyl	NR	NR	R	.	.	R	.	.	.	R	R	R	.	.	.	R	R	.	R	R	.	.	.	R	R	R	.	.	.	.	.	.	R	NR
Alum	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Alum Ammonium	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Alum Chloride	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Alum Potassium	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Aluminum Chloride	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Aluminum Fluoride	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Aluminum Hydroxide	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	R	.	R	R	R	.	.	.	.	.	.	.	R	R
Aluminum Hydroxide 10%	R	R	.	.	.	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	R	R
Aluminum Hydroxide 25%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	R	R
Aluminum Hydroxide 25%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	R	R
Aluminum Metaphosphate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Nitrate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Nitrate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Oxide	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Sulfate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Sulfate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Sulfide	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Aluminum Thiocyanate	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Ammonia Gas Dry	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Ammonia Aque 10%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	.	.	R	R	R	NR	NR
Ammonia Liquid	NR	NR	R	NR	NR
Ammonium Acetate	R	R	R	R	R	R	R	R	R	R	.	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Ammonium Bismuthate	R	R	R	R	R	R	R	R	NR	R	R	R																							



GROUND WATER SAMPLING, INC.
1855 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

[illegible]



GROUND WATER CONSULTING, INC
1855 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

[illegible]

CHEMICAL RESISTANCE OF PIPING MATERIALS



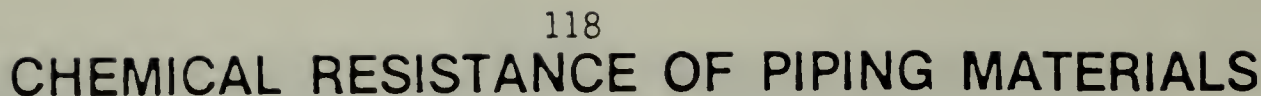
GROUND WATER CARTRIDGES, INC.
1855 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

CHEMICAL See Remarks On Page	PVC		CPVC			RENTON				POLY ETHYL ENE		POLYPROPYLENE				KYNAR			FIBERGLASS REINFORCED EPOXY				FIBERGLASS REINFORCED POLYESTER				FIBERGLASS REINFORCED VINYLESTER				VITON	
	70	140	70	140	185	80	150	220	250	70	120	70	120	150	180	70	150	250	70	150	225	250	70	120	150	250	70	100	150	200	70	185
Methyl Sulfate	R	*	*	*	*	NR	NR	NR	NR	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Methyl Sulfonic Acid	R	R	R	R	R	*	*	*	*	R	R	R	R	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Methylene Chloride	NR	NR	NR	NR	NR	R	R	R	*	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	*	*	*	*	NR	NR	NR	NR	NR	NR	NR	R	NR
Methylene Iodine	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Methylisobutyl Carbamate	*	*	*	*	*	*	*	*	*	*	*	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Milk	R	R	R	R	*	*	*	*	*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Mineral Oil	R	R	R	R	R	R	R	R	R	*	*	R	*	NR	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Molasses	R	H	R	R	R	R	R	R	R	*	*	R	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Murethanolamine	*	*	*	*	*	R	R	R	*	*	*	R	R	R	*	R	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mutor Oil	R	R	R	R	R	R	R	R	R	*	*	R	R	R	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Naphtha	R	R	R	R	*	R	R	R	R	NR	NR	R	*	*	*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Naphthalene	NR	NR	NR	NR	NR	R	R	*	*	R	R	R	*	*	*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Natural Gas	R	R	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nitral Acetate	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nitral Chloride	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Nitral Nitrate	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Nitral Sulfate	R	R	R	R	H	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Nitraline	R	R	*	*	*	*	*	*	*	R	R	R	R	R	*	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nitraline Acid	R	R	R	R	R	R	R	R	R	R	R	R	R	R	*	R	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Nitric Acid 10%	R	R	R	R	R	R	R	R	NR	R	*	R	R	R	R	*	*	*	R	*	*	*	*	R	R	R	*	*	*	*	*	*
Nitric Acid 30%	R	R	R	R	R	R	NR	NR	NR	*	*	R	R	R	R	*	*	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitric Acid 40%	R	R	R	NR	NR	R	NR	NR	NR	NR	NR	R	NR	NR	NR	*	*	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitric Acid 50%	R	R	R	NR	NR	R	NR	NR	NR	NR	NR	R	NR	NR	NR	*	*	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitric Acid 70%	R	H	H	NR	NR	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	*	*	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitric Acid 100%	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*
Nitrobenzene	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	R	*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nitroglycerine	NR	NR	*	*	*	R	*	*	*	*	*	NR	NR	NR	NR	R	R	*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Nitrous Acid 10%	*	*	*	*	*	R	R	*	*	*	*	NR	NR	NR	NR	R	R	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitrous Oxide	H	H	H	H	*	H	H	R	NR	*	*	R	*	*	*	*	*	*	NR	NR	NR	NR	R	*	*	*	*	*	*	*	*	*
Nitroxyco	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Oil Vegetable	R	R	R	R	R	R	H	R	R	*	*	R	R	*	*	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Oleic Acid	R	R	R	R	R	R	R	R	R	R	R	R	R	NR	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Oleum	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Oxalic Acid 50%	H	R	R	R	R	R	R	R	R	*	*	R	R	*	*	R	*	*	R	*	*	*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Oxygen Gas	H	R	R	R	R	R	H	R	R	NR	NR	NR	NR	NR	NR	R	R	R	R	R	R	*	*	*	*	*	*	*	*	*	*	*
Ozone	R	R	R	R	R	*	*	*	*	NR	NR	NR	NR	NR	NR	R	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Palmic Acid	*	*	*	*	*	R	R	R	R	NR	*	R	R	R	R	R	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Palmic Acid 10%	R	R	R	R	*	R	R	R	R	R	R	R	R	R	R	*	*	*	*	*	*	*	*	R	R	R	*	*	*	*	*	*
Palmic Acid 70%	H	NR	R	R	*	R	R	R	R	R	R	R	R	R	R	*	*	*	*	*	*	*	*	R	R	R	*	*	*	*	*	*
Paraffin	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Peracetic Acid 40%	R	NR	NR	NR	NR	*	*	*	*	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Perchloroethylene	*	*	*	*	*	*	*	*	*	*	*	NR	NR	NR	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Perchloric Acid 10%	R	R	R	R	*	R	R	R	R	R	R	R	R	R	R	R	R	*	R	R	R	*	*	*	*	*	*	*	*	*	*	*
Perchloric Acid 70%	R	NR	R	R	*	NR	NR	NR	NR	R	R	R	R	R	R	R	R	*	R	R	R	*	*	*	*	*	*	*	*	*	*	*
Phosphoric	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Petroleum Gas Refined	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Petroleum Oils Sol.	R	NR	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Phenol	R	NR	R	R	*	R	NR	NR	NR	*	*	R	R	R	R	R	R	*	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Phenylhydrazine	NR	NR	NR	NR	NR	R	H	NR	NR	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Phenylhydrazine Hydrochloride	R	NR	R	R	H	R	H	R	NR	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Phosgene Gas	R	R	*	*	*	R	NR	NR	NR	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	NR	NR
Phosgene Liquid	NR	NR	NR	NR	NR	R	NR	NR	NR	*	*	NR	NR	NR	NR	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	NR	NR
Phosphoric Acid 10%	R	R	R	R	R	R	R	R	R	R	R</																					



GROUND WATER SAMPLING, INC.
1855 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

CHEMICAL	PVC	CPVC	PENTON	POLYETHYLENE	POLYPROPYLENE	KYNAR	FIBERGLASS REINFORCED EPOXY	FIBERGLASS REINFORCED POLYESTER	FIBERGLASS REINFORCED VINYLESTER	VITON
See Remarks On Page	70 140	70 140 185	80 150 220 250	70 120	70 120 150 180	70 150 250	70 150 225 250	70 120 150 250	70 100 150 200	70 1B ¹
Potassium Chlorate	R R	R R R	R R R R R	R R	R R R R	R R R	R . . .	. . . .	. . . .	R R
Potassium Cyanide	R R	R R R	R R R R R	R R	R R R R	R R R	R . . .	. . . .	. . . .	R R
Potassium Dichromate	R R	R R R	R R R NR	R R	R R R R	R R R	R . R R	R R R R	R R R R	R R
Potassium Ethyl Xanthate	R NR	. . .	. . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Potassium Ferricyanide	R R	R R R	R R R R	R R	R R . .	. . .	R R R .	R R R R	R R R R	R R
Potassium Ferrocyanide	R R	R R R	R R R R	R R	R R R R	R R R	R R . .	R R R R	. . . .	R R
Potassium Fluoride	R R	R R R	R R R R	R R	R R R .	. . .	. . . .	. . . .	. . . .	R R
Potassium Hydroxide 25%	R R	R R R	R R R R	NR NR	R R R R	. . .	R . . .	NR NR NR NR	R R . .	NR NR
Potassium Hypochlorite	R R	. . .	R R R .	. . .	. . . .	. . .	. . . .	NR NR NR NR	R R R .	NR NR
Potassium Iodide	. . .	. . . .	. . . .	. . .	R . . .	. . .	. . . .	. . . .	. . . .	. . .
Potassium Nitrate	R R	R R R	R R R R	R NR	R R R .	R R R	R R R R	R R R R	R R R R	R R
Potassium Perchlorate	R R	R R R	R R R NR	R R	. . .	. . .	. . . .	. . . .	. . . .	. . .
Potassium Perochlorate	R R	R R R	R R R NR	R R	. . .	. . .	. . . .	. . . .	. . . .	. . .
Potassium Permanganate 10%	R R	R R R	R R NR NR	R R	R R R .	. . .	R . . .	R R R R	R R R R	. . .
Potassium Permanganate 25%	R NR	R R .	. . NR NR	R .	R R R .	R R R	R R NR NR	R R R .	R R R R	. . .
Potassium Persulfate	R R	. . .	R R R NR	R R	R R R .	. . .	R R R .	R R R R	R R R R	. . .
Potassium Sulfate	R R	R R R	R R R R	R R	R R R R	R R R	R R R R	R R R R	R R R R	R R
Potassium Sulfide	R R	. . .	. . . .	R NR	R R R R	R R R	. . . .	. . . .	. . . .	R R
Propene	R R	R R .	R R R R	R R	R R R .	R R R	R . . .	. . . .	. . . .	R R
Propylene Dichloride	NR NR	NR NR NR	R NR NR NR	NR NR	NR NR NR NR	. . . .	. . . .	. . . .	. . . .	. . .
Propylene Glycol	. . .	. . . .	. . . .	. . .	. . . .	. . .	R . . .	. . . .	. . . .	. . .
Propylene Oxide	NR NR	. . . .	. . . .	. . .	. . . .	NR NR NR	. . . .	. . . .	. . . .	NR NR
Pyridine	NR NR	. . . .	R R R .	. . .	. . . .	NR NR NR	NR NR NR NR	NR NR NR NR	. . . .	NR NR
Pyrogallol Acid	R NR	. . . .	. . . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Salicylic Acid	R P	. . . .	R R R .	. . .	. . . .	R R .	. . . .	. . . .	. . . .	R R
Salicylaldehyde	. . .	. . . .	R . . .	. . .	. . . .	R R NR	. . . .	. . . .	. . . .	. . .
Selenic Acid	R R	. . . .	. . . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Silicic Acid	R R	. . . .	. . . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Silicone Oil	. . .	. . . .	. . . .	. . .	R R R .	. . .	. . . .	. . . .	. . . .	R R
Silver Chloride	. . .	. . . .	. . . .	R R	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Silver Cyanide	R R	R R R	R R R R	R R	R R R R	R R R	R . . .	R R R R	R R R R	R R
Silver Nitrate	R R	R R R	R R R R	R R	R R R R	R R R	R . . .	R R R R	R R R R	R R
Silver Sulfate	R R	. . . .	. . . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	R R
Soda	R R	P R R	R R H R	R R	R R R .	. . . .	R R R .	. . . .	. . . .	R R
Sodium Acetate	R R	R R R	R R R R	R R	R R R R	R R R	R R R .	R R R R	R R R R	NR NR
Sodium Alum	R R	. . . .	. . . .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Sodium Benzoate	R R	R R R	R R R R	R R	R R R R	R R R	R R R .	R R R R	R R R R	. . .
Sodium Bicarbonate	R R	R R R	R R R R	R R	R R R R	R R R	R R R .	R R R R	R R R R	R R
Sodium Bichromate	R R	. . . .	R R R .	. . .	. . . .	. . .	. . . .	. . . .	. . . .	. . .
Sodium Bisulfate	R R	R R R	R R R R	R R	R R R R	R R R	R R R R	R R R R	R R R R	R R
Sodium Bisulfite	R R	R R R	R R R R	R .	R R R R	R R R	R R R .	R R R R	R R R R	R R
Sodium Borate	R .	. . . .	R R R R	. . .	R . . .	. . .	. . . .	. . . .	. . . .	R R
Sodium Bromide	R R	R R R	P R R R	R R	R R R R	R R R	R R R .	R R R R	R R R R	. . .



GROUND WATER SAMPLING
1855 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

CHEMICAL	PVC		CPVC		PENTON				POLY ETHYL ENE		PDLYPROPYLENE				KYNAR			FIBERGLASS REINFORCED EROXY				FIBERGLASS REINFORCED ADLYESTER				FIBERGLASS REINFORCED VINYLESTER				VITON			
	70	140	70	140	185	80	150	220	250	70	120	70	120	150	180	70	150	250	70	150	225	250	70	120	150	250	70	100	150		200	70	100
See Remarks On Page																																	
Sulfur Liquors	R	R	R	R	R	R	R	R	R	R	R	NR	NR	NR	NR	R	R	R	R	R	NR	NR	NR	R	R	R	R	R	R	R	R	R	
Sulfur	R	R	R	R	R	R	R	R	R	R	R	NR	NR	NR	NR	R	R	R	R	R	NR	NR	NR	R	R	R	R	R	R	R	R	R	
Sulfur Chloride	.	.	.	.	.	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	R	.	NR	NR	NR	NR	R	R	R	R	.	.	.	.	.	NR
Sulfur Dioxide Dry	R	R	R	R	.	R	.	.	.	R	.	.	.	.	.	R	R	.	R	R	R	.	R	R	R	R	.	.	.	.	.	NR
Sulfur Dioxide Wet	R	NR	R	R	R	R	R	R	NR	NR	NR	.	.	.	.	R	R	.	R	R	.	.	R	R	R	.	.	.	.	.	.	NR
Sulfur Trioxide	R	R	.	.	.	R	.	NR	NR	NR	NR	NR	NR	NR	NR	R	NR	NR	NR	NR	NR	NR	R	R	R	.	.	.	.	.	.	R
Sulfur Trioxide Gas	R	R	.	.	.	R	R	.	.	.	.	.	.	.	.	.	.	.	R	R	.	NR	R	R	R	R	R	R	R	R	R	R
Sulfuric Acid 10%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	NR	R	R	R	R	R	R	R	R	R	R	
Sulfuric Acid 30%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	.	.	.	R	R	.	NR	R	R	R	R	R	R	R	R	R	R	
Sulfuric Acid 50%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	NR	.	.	.	R	R	.	NR	R	R	R	R	R	R	R	R	R	R	
Sulfuric Acid 60%	R	R	R	R	R	R	R	R	R	R	.	R	R	R	NR	R	R	.	R	R	NR	NR	R	R	R	NR	R	R	R	R	R	R	
Sulfuric Acid 70%	R	R	R	R	R	R	R	R	R	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	R	R	R	NR	R	R	R	R	R	R	
Sulfuric Acid 80%	R	R	R	R	R	R	R	R	R	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	R	NR	NR	NR	R	R	R	R	R	R	
Sulfuric Acid 90%	R	NR	R	NR	NR	R	R	NR	NR	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	NR	NR	NR	NR	NR	R	.	.	.	R	
Sulfuric Acid 93%	R	NR	R	NR	NR	R	R	NR	NR	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	
Sulfuric Acid 94%	NR	NR	R	NR	NR	R	NR	NR	NR	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	R
Sulfuric Acid 95%	NR	NR	NR	NR	NR	R	NR	NR	NR	R	.	R	R	NR	NR	R	R	.	R	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	R
Sulfuric Acid 96%	NR	NR	NR	NR	NR	R	NR	NR	NR	R	.	R	R	NR	NR	.	.	.	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	R
Sulfuric Acid 98%	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	NR	NR	NR	NR	R	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	R
Sulfuric Acid 100%	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	NR	NR	NR	NR	.	.	.	NR	NR	NR	NR	NR	NR	NR	NR	NR	.	.	.	.	R
Sulfurous Acid	R	R	R	R	R	R	R	R	NR	NR	.	R	R	.	.	R	R	.	R	R	NR	NR	R	R	R	.	.	.	.	.	.	R
Tall Oil	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	R	R	R	.	.	.	.	R	R	R	.	.	.	.	.	.	.
Tannic Acid	R	R	R	R	R	R	R	R	R	.	.	R	R	R	R	R	R	R	R	R	.	.	R	R	R	R	R	R	R	R	R	R	
Tanning Liquors	R	R	R	R	R	R	R	R	R	R	.	R	R	.	.	R	R	.	R	R	.	.	R	R	R	R	R	R	R	R	R	R	
Tar	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tartaric Acid	R	R	R	R	R	R	R	R	R	R	.	R	R	R	.	R	R	R	R	R	H	.	R	R	H	R	R	R	R	R	R	R	
Tetramethyl Lead	R	.	.	.	.	H	R	H	NH	.	.	H	.	.	.	R	R	H	R	H	.	.	.	.	.	.	.	.	.	.	.	.
Tetrahydrofuran	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tetrahydrothiolate	NR	NR	NP	NR	NR	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tetra Sodium Pyrophosphate	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Thionyl Chloride	NR	NR	NR	NR	NR	NR	NR	NR	NH	NR	NR	R	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Thread Cutting Oils	R	.	.	.	.	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tin Chloride	R	R	R	R	R	.	.	.	.	.	.	R	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Tripnead	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Titanium Tetrachloride	R	NR	.	.	.	R	NR	NR	NR	R	R	R	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Toluene Toluol	NR	NR	NR	NR	NR	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	R	.	R	R	.	.	R	R	R	.	R	.	.	.	.	R
Tomato Juice	.	.	.	.	.	R	R	R	R	.	.	H	R	R	R	.	.	.	R	.	R	.	.	.	.	.	.	.	.	.	.	R
Transformer Oil	R	.	.	.	.	.	.	.	.	.	.	R	R	NR	NR	.	.	.	H	R	R	NH	.	.	.	.	.	.	.	.	.	R
Transformer Oil DTE 30	.	.	.	.	.	.	.	.	.	.	.	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Triallyl Phosphate	NR	NR	NR	NR	NR	R	R	R	NR	.	.	R	.	NR	NR	R	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	NR
Triallyl Citrate	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Trichloroacetic Acid	.	.	.	.	.	NR	NR	NR	NR	.	.	R	R	R	.	R	NR	NR	R	R	.	.	R	R	R	.	R	R	R	.	NR	
Trichloroethylene	NR	NR	NR	NR	NR	R	R	NR	NR	NR	NR	R	NR	NR	NR	R	R	R	R	R	.	.	R	R	R	.	.	.	.	.	.	R
Triethanolamine	R	NH	.	.	.	R	R	R	NR	NR	NR	R	R	R	R	.	.	.	R	R	.	.	R	R	.	.	.	.	.	.	.	NR
Trimethylamine	R	R	.	.	.	R	R	R	NR	.	.	NR	NR	NR	NR	R	R	.	R	NR	NR	NR	.	.	.	.	.	.	.	.	.	R
Trimethylpropylamine	R	R	R	R	.	R	R	H	R	.	.	NR	NR	NR	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R
Trisodium Phosphate	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	R	R	R	R	R	.	.	R	R	R	R	R	R	R	R	R	R	
Turpentine	H	R	R	.	.	R	R	R	.	R	R	R	NP	NR	NR	R	R	R	R	R	NR	NR	.	.	.	.	.	.	.	.	.	R
Urea	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	R	R	R	.	.	.	.	.	.	R
Urine	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R
Vaseline	.	.	.	.	.	.	.	.	.	.	.	R	R	R	NR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Vegetable Oil	R	R	R	R
Vinegar	R	R	R	R	NR	R	R	R	R	R	R	R	R	R	.	.	.	.	R	.	.	.	.	.	.	.	.	.	.	.	.	R
Vinegar White	R	R	R	R	.	.	R	R	R	R
Vinyl Acetate	NR	NR	NR	NR	NR	R	R	NR	NR	NR	NR	NR	NR	NR	NR	R	R	R	R	R	.	.	R	R	R	R	R	R	R	R	R	R	
Water	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Water Acid Mine	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Water Demineralized	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Water Distilled or Fresh	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Water Potable	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Water Sale	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	R	R	R	R	.	.	.	.	.	.	.	.	.	R
Water Sea	R	R	R	R	R	R	R	R	R	.	.	R	R	R	R	R	R	R	R	R	R	.	.	R	R	R	.	.	.	.	.	R
Water Sewage	R	R	R	R	R	R	R	R	R	R
Whiskey	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R
White Liquid	R	R	R	R	R	R	R	R	NR	.	.	.	.	.	.	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	R
Wines	R	R	R	R	R	R	R	R	R	R	R	R	R	R	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	R
Xylene Xylol	NR	NR	NR	NR	NR	R	NR	NR	NR	NR	NR	NR	NR	NR	NR	R	R	.	R	R	.	.	R	R	R	.	.	.	.	.	.	R
Zinc Chloride	R	R	R	R	R	R	R	R	NR	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	
Zinc Nitrate	R	R	R	R	R	R	R	R	NR	R	R	R	R	R	R	R	R	R	NR	NR	NR	NR	R	R	R	R	R	R	R	R	R	R	
Zinc Sulfate	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	

CHEMICAL RESISTANCE CHART

119

RATINGS—CHEMICAL EFFECT

A—No effect—Excellent
B—Minor effect—Good
C—Moderate effect—Fair
D—Severe effect—Not recommended

EXPLANATION OF FOOTNOTES

1. P.V.C.—Satisfactory to 72°F.
2. Polypropylene—Satisfactory to 72°F.
3. Polypropylene—Satisfactory to 120°F.
4. Buna-N—Satisfactory for O-Rings
5. Polyacetal—Satisfactory to 72°F.
6. Ceramag—Satisfactory to 72°F

Table A I-2. Chemical resistance chart.

	EPOXY	POLYPROPYLENE	POLYETHYLENE	PVC (Type 1)	CYCOLAC (ABS)	PHENOLIC	NYLON	NORYL	POLYACETAL	RYTON 200°F	TEFLON	STAINLESS (316)	STAINLESS (304)	STAINLESS (440)	TITANIUM	CAST BRONZE	CAST IRON	ALUMINUM	HASTELLOY C	CARBON CERAMIC	CERAMIC	CERAMAGNET "A"	VITON	BUNA N	NEOPRENE	NITRILE	RUBBER (Nat.)	HYALON	KELF	TYGON (E-3603)
Acetaldehyde ¹	A	B	C	D	D	-	A	-	A	A	A	A	B	-	A	D	-	B	A	A	A	-	D	D	C	D	C	C	B	D
Acetamide	A	A	D	B	B	-	A	-	B	-	-	A	B	B	-	A	-	B	-	A	A	-	B	A	D	D	D	D	A	D
Acetate Solv. ¹	A	D	B	B	-	-	A	-	A	-	-	A	B	B	-	A	-	B	-	A	A	-	B	A	D	D	D	D	A	D
Acetic Acid, Glacial ¹	B	B	B	C	D	-	D	C	D	A	A	A	B	A	A	C	D	B	A	A	A	-	D	C	D	C	C	C	-	B
Acetic Acid 20%	B	A	-	B	-	-	D	A	-	A	A	A	-	-	A	-	-	-	A	-	A	-	B	B	A	B	B	A	-	A
Acetic Acid 80%	B	B	B	B	C	-	D	B	-	A	A	A	B	B	A	C	D	B	A	A	A	-	D	C	D	C	C	C	A	B
Acetic Acid	A	A	A	A	D	-	D	D	D	A	A	A	A	B	A	C	D	B	A	A	A	-	D	C	D	C	C	C	A	B
Acetic Anhydride	A	A	A	A	D	-	D	D	D	A	A	A	A	B	A	C	D	B	A	A	A	-	D	C	D	C	C	C	A	B
Acetone ¹	B	B	C	D	D	-	A	A	D	B	A	A	A	B	A	A	-	-	A	A	A	-	D	D	D	D	D	B	A	D
Acetyl Chloride	A	-	-	-	-	-	-	-	-	-	-	-	C	-	-	D	-	-	-	-	-	-	A	D	D	D	D	D	-	D
Acetylene ¹	A	D	-	B	-	-	A	-	A	A	-	A	A	-	B	-	A	-	A	-	A	-	A	B	B	B	B	B	-	-
Acrylonitrile	A	B	-	-	D	-	-	-	B	A	-	A	A	-	-	A	-	B	B	A	A	-	D	D	D	-	D	-	-	-
Alcohols																														
Amyl	A	B	B	A	B	-	A	C	A	A	A	A	-	A	A	-	B	A	A	A	A	-	B	B	A	B	B	A	-	B
Benzyl	A	A	D	D	D	-	A	A	A	-	-	A	A	-	-	-	-	B	B	A	A	-	A	D	B	D	D	B	-	B
Butyl	A	B	B	A	-	-	A	A	A	A	-	A	A	-	-	B	-	B	A	A	A	-	A	A	A	A	A	A	A	B
Diacetone ¹	A	D	-	D	-	-	A	A	A	-	-	A	A	-	-	A	-	A	A	A	A	-	D	D	D	D	D	D	-	-
Ethyl	A	A	B	A	B	-	A	A	B	-	-	A	A	-	A	A	-	A	B	A	A	-	A	C	A	C	A	A	-	C
Hexyl	A	A	-	A	-	-	A	A	A	-	-	A	A	-	-	A	-	A	A	A	A	-	A	A	B	A	A	A	-	-
Isobutyl	A	A	-	A	B	-	A	A	A	-	-	A	A	-	-	A	-	B	A	A	A	-	A	B	A	B	A	A	-	-
Isopropyl	A	A	-	A	-	-	A	A	A	-	-	A	A	-	-	A	C	B	A	A	A	-	A	B	B	B	A	A	-	-
Methyl ¹	A	A	B	B	D	-	A	A	C	-	-	A	A	-	A	A	A	B	A	A	A	-	D	A	A	A	A	A	-	-
Octyl	A	-	-	-	-	-	A	A	A	-	-	A	A	-	-	A	-	A	A	A	A	-	A	B	B	B	B	B	-	-
Propyl	A	A	-	A	-	-	A	A	A	-	-	A	A	-	-	A	-	A	A	A	A	-	A	A	A	A	A	A	-	-
Aluminum Chloride 20%	A	A	B	A	-	-	A	A	C	A	-	C	D	D	-	D	D	B	A	A	A	-	A	A	A	A	A	-	-	B
Aluminum Chloride	A	A	-	A	-	-	D	A	-	A	A	C	D	-	C	C	D	D	A	A	A	-	A	A	A	A	A	A	B	-
Aluminum Fluoride	A	A	B	A	-	-	D	A	C	-	-	C	D	D	-	-	-	B	A	-	-	-	A	A	A	A	B	A	-	-
Aluminum Hydroxide ¹	A	A	-	A	-	-	A	A	B	-	-	A	A	-	-	A	D	A	B	A	A	-	A	A	A	A	A	A	-	-
Alum Potassium Sulfate (Alum), 10%	A	A	-	A	-	-	A	A	-	-	-	A	A	-	-	-	D	A	B	A	A	-	A	A	A	A	A	-	-	-
Alum Potassium Sulfate (Alum) 100%	A	A	B	A	-	-	D	A	C	-	-	A	A	D	B	-	C	B	B	A	A	-	A	A	A	A	A	-	-	B
Aluminum Sulfate	A	A	B	A	-	-	A	A	C	A	-	A	C	C	A	C	D	A	A	A	A	-	A	A	A	A	A	A	-	A
Amines	A	-	-	C	-	-	A	B	D	-	-	A	A	-	B	B	A	A	A	A	A	-	D	D	B	D	B	D	-	A
Ammonia 10%	B	A	-	A	-	-	A	A	-	-	-	A	A	-	-	A	-	-	A	-	-	-	A	D	A	-	-	-	-	A
Ammonia, Anhydrous	A	A	B	A	-	-	A	A	D	B	-	A	A	B	A	B	D	D	B	A	C	-	B	B	A	B	D	D	-	B
Ammonia, Liquids	A	A	D	A	-	-	A	A	D	-	-	A	A	A	-	D	A	D	B	A	-	-	D	B	A	-	D	-	-	B
Ammonia, Nitrate	A	A	-	B	-	-	A	-	A	C	-	-	A	A	-	D	-	C	-	A	A	-	-	A	C	A	-	-	-	B
Ammonium Bifluoride	A	A	-	A	-	-	A	D	-	-	-	A	C	-	-	-	-	D	B	-	-	-	A	A	A	A	-	-	-	-
Ammonium Carbonate	A	A	-	A	-	-	A	A	D	-	-	A	A	-	A	B	C	C	B	A	-	-	D	D	A	D	A	-	-	B
Ammonium Caseinate	A	A	-	A	-	-	A	A	D	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ammonium Chloride	A	A	B	A	-	-	A	A	B	A	-	A	A	-	A	D	D	C	A	-	-	-	A	A	A	A	-	-	-	B
Ammonium Hydroxide	A	A	B	A	B	A	A	A	D	A	-	A	A	-	A	D	A	C	A	A	-	-	B	-	A	D	D	A	-	A
Ammonium Nitrate	A	A	B	A	-	-	A	A	C	A	-	A	A	-	A	D	A	B	A	A	-	-	A	A	B	A	C	A	-	B
Ammonium Oxalate	A	-	-	-	-	-	-	-	B	-	-	A	A	-	-	-	-	-	A	A	-	-	-	A	A	-	-	-	-	-
Ammonium Persulfate	A	A	-	A	-	-	C	D	A	D	-	A	A	-	-	A	D	C	A	A	-	-	-	A	D	A	A	-	-	-
Ammonium Phosphate, Dibasic	A	A	B	A	-	-	A	A	B	-	-	A	A	-	-	A	C	-	B	A	-	-	-	A	A	A	A	-	-	A
Ammonium Phosphate, Monobasic	A	A	B	A	-	-	A	A	B	-	-	A	A	-	-	A	D	-	B	A	-	-	-	A	A	A	A	-	-	A
Ammonium Phosphate, Tribasic	A	A	B	A	-	-	A	A	B	-	-	A	A	-	-	A	C	C	B	A	-	-	-	A	A	A	A	-	-	A
Ammonium Sulfate	A	A	B	A	-	-	A	A	B	A	-	A	A	-	-	A	B	C	B	A	-	-	-	A	A	A	A	-	-	A
Ammonium Thio-Sulfate	A	-	-	-	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amyl-Acetate	A	D	D	D	-	-	B	D	A	A	-	A	A	-	A	A														

GROUND WHITE SANDS INC.
1555 W. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

	EPOXY	POLYPROPYLENE	POLYETHYLENE	PVC (Type 1)	CYCOLAC (ABS)	PHENOLIC	NYLON	NORYL	POLYACETAL	RYTON 200°F	TEFLON	STAINLESS (316)	STAINLESS (304)	STAINLESS (440)	TITANIUM	CAST BRONZE	CAST IRON	ALUMINUM	HASTELLOY C	CARBON CERAMIC SE	CERAMIC	CERAMAGNET "A"	VITON	BUNA N	NEOPRENE	NITRILE	RUBBER (Nat.)	HYALON	KEL-F	TYGON (F-340)	
Butter	A	-	-	B	-	-	B	A	-	-	A	B	-	-	D	D	A	-	A	A	-	A	A	A	B	A	D	B	-	B	
Buttermilk	A	-	-	B	-	-	A	A	D	-	A	A	A	-	D	-	A	-	A	-	A	-	A	A	A	D	D	-	-	B	
Butylene	A	D	C	D	-	D	-	A	A	A	A	C	-	-	-	-	A	-	A	A	-	D	D	D	D	D	D	-	-	D	
Butyl Acetate	A	A	-	B	D	A	D	A	C	-	A	B	A	A	C	D	-	B	A	A	D	-	B	D	D	D	D	-	-	-	
Butyric Acid	A	A	-	B	D	A	D	A	C	-	A	B	A	A	C	D	-	B	A	A	D	-	B	D	D	D	D	-	-	-	
Calcium Bleulfite	A	-	-	A	-	-	A	-	-	-	-	A	D	-	D	-	D	-	D	-	-	-	A	-	C	-	A	-	-	A	
Calcium Bleulfide	A	A	B	A	-	-	A	A	D	-	A	B	-	-	A	C	-	C	A	A	-	A	A	A	A	A	D	A	-	-	
Calcium Bleulfite	A	-	-	A	-	B	A	-	-	-	-	A	D	-	A	C	-	C	A	-	A	-	A	A	A	B	A	-	-	A	
Calcium Carbonate	A	A	-	A	-	-	A	-	-	-	-	A	A	A	A	C	-	C	A	-	A	-	A	A	A	A	A	-	-	A	
Calcium Chloride	A	A	B	A	B	A	A	A	D	A	A	D	A	C	A	B	C	C	A	A	A	B	A	A	A	A	A	A	A	A	
Calcium Hydroxide	A	A	B	A	-	D	A	A	B	-	A	A	A	-	A	B	-	C	A	A	A	A	A	A	A	A	A	A	A	A	
Calcium Hypochlorite	A	A	B	D	-	A	D	A	D	-	A	C	A	C	A	D	D	C	B	B	A	A	-	A	D	C	D	D	A	-	
Calcium Sulfate	A	A	B	A	C	-	A	A	A	A	A	A	A	A	A	B	-	B	B	A	A	-	A	A	D	-	C	A	-	-	
Calgon	A	A	-	-	-	-	A	B	-	-	-	A	-	-	-	C	D	-	-	A	-	A	A	A	A	A	-	-	-	-	
Cane Juice	A	D	-	A	-	A	A	-	-	-	-	A	A	-	B	A	B	-	A	A	-	A	A	A	A	A	A	A	-	-	
Carbolic Acid (See Phenol)	A	D	-	A	-	A	A	-	-	-	-	A	A	-	C	-	A	-	A	A	-	A	A	A	D	C	D	D	C	B	
Carbon Bleulfide	A	A	-	A	B	-	A	A	A	-	-	A	A	A	-	A	D	A	-	A	-	B	A	B	-	C	B	-	-	D	
Carbon Dioxide	A	-	-	D	-	-	-	-	-	-	-	A	A	A	-	A	-	A	A	-	-	B	A	-	A	-	B	-	-	D	
Carbon Dioxide (Dry)	-	-	-	-	-	-	-	-	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Carbon Dioxide (Wet)	-	-	-	-	-	-	-	-	-	-	-	A	A	A	-	-	C	C	C	A	A	A	-	B	A	-	A	-	-	-	
Carbon Disulfide	A	D	D	D	-	A	D	A	A	A	A	B	-	-	-	C	B	C	-	A	B	-	A	D	D	D	D	D	A	C	
Carbon Monoxide	A	-	B	A	-	-	A	B	A	-	-	A	A	-	-	-	-	-	-	-	A	-	A	A	A	A	B	A	-	-	
Carbon Tetrachloride	C	D	D	C	D	-	A	D	A	A	A	B	C	A	A	C	C	C	A	A	A	A	A	C	D	D	D	D	A	C	
Carbonated Water	A	-	-	A	-	-	A	A	A	-	-	A	A	A	-	B	D	A	-	A	A	-	A	A	A	-	-	-	-	-	
Carbonic Acid	A	A	B	A	-	A	A	A	A	-	-	A	B	A	A	-	B	D	A	A	A	-	A	B	A	D	A	A	-	-	
Caustic	A	A	-	B	-	-	A	A	B	-	-	A	A	A	-	C	D	D	-	A	A	-	A	A	C	A	D	D	-	-	
Chloroacetic Acid	A	D	D	A	-	D	-	D	-	-	-	A	D	D	A	D	D	C	A	A	-	A	D	D	D	D	D	-	-	-	
Chloric Acid	A	-	-	D	-	C	C	-	-	-	-	A	A	-	-	C	D	D	-	-	A	-	A	C	D	-	D	-	-	-	
Chlorinated Glue	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Chlorine, Anhydrous Liquid	B	D	D	D	-	-	D	A	D	C	A	D	D	D	D	D	C	D	A	A	D	-	A	D	D	D	D	D	C	-	B
Chlorine (Dry)	D	-	-	-	-	D	-	-	-	C	A	A	A	-	D	A	A	D	A	A	A	-	D	-	D	D	D	D	A	B	
Chlorine Water	-	D	-	A	-	-	D	C	-	C	A	D	-	-	-	-	-	B	-	A	-	A	D	D	D	D	D	-	-	-	
Chlorobenzene (Mono)	A	D	D	D	D	-	A	D	A	A	A	A	A	A	A	B	D	D	A	A	A	A	A	D	D	D	D	D	-	-	
Chloroform	A	D	D	D	D	A	C	D	A	A	A	A	A	A	A	B	D	D	A	A	A	A	A	D	D	D	D	D	-	-	
Chlorosulfonic Acid	C	D	D	C	-	D	D	D	D	A	D	D	D	D	A	D	D	C	B	-	C	-	D	D	D	D	D	D	-	-	
Chlorox (Bleach)	A	D	-	A	B	D	A	A	D	C	-	A	A	-	-	A	D	C	A	A	-	A	C	B	C	D	B	-	-	-	
Chocolate Syrup	A	A	-	A	-	-	A	A	A	-	-	A	A	-	-	-	-	D	C	A	-	A	A	-	-	D	-	-	-	-	
Chromic Acid 5%	B	A	B	A	B	C	D	C	D	A	-	A	A	B	A	D	D	C	A	D	C	-	A	D	D	D	B	B	-	-	
Chromic Acid 10%	C	A	-	A	-	-	D	A	-	-	-	A	B	-	-	A	-	-	-	A	-	A	D	D	D	D	B	-	-	-	
Chromic Acid 30%	D	A	-	A	-	-	D	D	-	-	-	A	B	-	-	A	-	-	-	A	-	A	D	D	D	D	C	-	-	-	
Chromic Acid 50%	C	B	C	B	C	C	D	D	D	B	A	B	B	-	-	A	D	D	C	A	D	A	-	A	D	D	D	D	C	-	-
Cider	A	-	B	A	-	-	-	A	B	-	-	A	A	A	-	-	A	D	C	A	A	A	B	A	D	A	A	A	-	-	
Citric Acid	A	B	B	A	C	-	A	C	A	B	-	A	A	A	A	A	D	D	C	A	A	A	A	D	A	A	A	A	-	-	
Citric Oxide	A	A	-	-	-	-	-	A	B	-	-	A	A	-	-	B	-	C	-	A	A	-	A	A	D	-	-	-	-	-	
Coffee	A	A	-	-	-	-	A	A	A	-	-	A	A	A	-	B	-	A	-	A	A	-	A	A	A	A	A	A	-	-	
Copper Chloride	A	A	B	A	-	D	D	A	B	A	A	D	D	B	A	D	D	D	A	A	-	A	A	A	A	A	A	A	-	-	
Copper Cyanide	C	A	B	A	-	A	A	A	B	A	A	A	A	A	A	C	D	D	D	B	A	-	B	B	A	A	A	-	-	-	
Copper Fluoborate	A	-	A	A	-	A	-	A	B	-	-	A	D	D	-	-	-	-	-	-	A	-	A	A	A	-	-	-	-	-	
Copper Nitrate	A	A	B	A	-	A	D	A	B	-	-	A	A	B	A	D	-	D	A	A	A	-	A	A	A	-	-	-	-	-	
Copper Sulfate (5% Solution)	A	A	B	A	-	D	A	B	A	A	A	A	A	A	A	D	D	D	A	A	A	-	A	A	A	A	C	A	-	-	
Copper Sulfate	A	A	-	A	-	A	C	A	-	-	-	A	B	-	-	A	-	-	-	A	-	A	-	B	B	A	A	-	-	-	
Cream	A	A	-	-	-	-	A	A	A	-	-	A	A	-	-	-	C	D	A	-	A	-	A	A	C	A	-	-	-	-	
Cresols	A	C	D	D	D	-	-	D	A	-	-	A	A	-	-	D	-	B	-	A	-	A	D	D	D	D	D	D	-	-	
Cresylic Acid	A	-	C	B	-	-	D	-	D	-	-	A	A	-	-	A	C	-	C	B	A	-	A	D	D	D	D	D	-	-	
Cyclohexane	A	D	-	-	-	B	-	D	A	A	-	A	-	-	-	A	A	-	A	-	A	-	A	-	C	D	A	D	-	-	
Cyanic Acid	A	A	-	-	-	-	-	D	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Detergents	A	A	B	A	B	B	A	A	B	A	-	A	A	-	-	-	-	-	-	-	-	-	A	B	A	C	B	C	-	-	
Dichloroethane	A	-	D	D	-	-	A	-	-	-	-	A	A	-	-	-	-	-	-	-	-	-	C	-	D	-	D	-	-	-	
Diesel Fuel	A	D	-	-	-	-	-	D	A	A	-	A	A	-	-	-	-	-	-	-	-	-	A	A	D	A	D	B	-	-	
Diethylamine	A	C	-	D	-	-	B	D	-	-	-	A	-	-	-	-	-	-	-	-	-	-	D	B	B	C	C	-	-	-	
Diethylene Glycol	A	-	B	-	B	-	A	A	A	-	-	A	-	-	-	-	-	-	-	-	-	-	A	A	D	A	A	-	-	-	
Diphenyl Oxide	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Dyes	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Epsom Salts (Magnesium Sulfate)	A	A	-	A	-	-	-	A	A	-	-	A	A	A	A	B	-	A	B	A	A	-	A	A	A	A	B	A	-	-	
Ethane	A	-	-	-	-	-	-	D	A	-	-	A	-	-	-	-	-	-	-	-	-	-	A	A	B	A	D	B	-	-	
Ethanolamine	A	-	-	-	-	-	-	D	A	-	-	A	-	-	-	-	-	-	-	-	-	-	D	B	B	B	C	C	-	-	
Ether	A	-	-	D	-	-	C	D	A	A	-	A	A	A	-	B	-	A	B	B	A	A	C	D	D	D	D	D	-	-	
Ethyl Acetate	A	C	C	D	D	A	A	D	A	A	A	A	A	A	-	B	-	B	B	B	A	-	A	D	C	A	A	D	A	-	
Ethyl Chloride	A	D	D	D	-	B	A	D	A	A	A	A	A	A	-	B	C	B	B	A	-	A	D	C	A	A	D	A	-	-	
Ethyl Sulfate	A	-	-	-	-	-	-	B	-	-	-	D	-	-	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-	
Ethylene Chloride	A	D	-	D	D	-	-	D	A	A	A	A	A	-	-	B	A	C	C	B	A	-	A	D	D	D	D	D	-	-	
Ethylene Dichloride	A	A	D	D	-	-	A	D	A	A	A	A	A	-	-	A	C	-	D	B	C	A	-	A	D	D	D	D	-	-	
Ethylene Glycol	A	D	B	A	B	A	A	A	A	A	A	A	A	-	-	B	B	A	A	A	-	A	D	D	D</						

GROU...
1955...
ENGLEWOOD, COLORADO 80110

	EPOXY	POLYPROPYLENE	POLYETHYLENE	PVC (Type 1)	CYCOLAC (ABS)	PHENOLIC	NYLON	NORLY	POLYACETAL	RYTON 200°F	TEFLON	STAINLESS (316)	STAINLESS (304)	STAINLESS (440)	TITANIUM	CAST BRONZE	CAST IRON	ALUMINUM	HASTELLOY C	CARBON CERAMIC SE	CERAMIC	CERAMAGNET "A"	VITON	BUNA N	NEOPRENE	NITRILE	RUBBER (Nat.)	HYALON	KEL-F	TYGON (E-3603)	
Formaldehyde 40%	A	A	B	-	-	D	A	-	-	A	A	-	-	-	A	-	-	-	A	-	A	-	D	C	A	C	C	C	-	-	
Formaldehyde	A	A	B	D	-	C	A	D	A	A	A	B	A	-	A	-	D	A	B	A	A	B	D	C	D	B	C	A	-	B	
Formic Acid	B	A	B	D	-	C	A	D	A	A	A	B	A	-	A	-	D	A	B	A	A	B	D	C	D	B	C	A	-	B	
Freon 11	A	-	C	B	D	C	A	D	A	A	-	A	-	-	-	B	C	C	B	-	A	A	C	C	D	D	D	A	-	D	
Freon 12 (wet)	A	A	C	B	B	D	A	D	A	A	A	D	-	-	-	B	-	B	-	A	A	A	A	A	B	C	D	A	-	D	
Freon 22	A	-	-	D	-	-	A	B	A	A	-	A	-	-	-	B	-	B	-	A	A	A	D	D	A	C	A	A	-	D	
Freon 113	A	-	-	C	-	-	A	-	A	A	-	A	-	-	-	B	-	B	-	A	A	A	C	A	A	C	D	A	-	D	
Freon T.F.	A	D	-	B	-	-	A	D	A	A	-	A	-	-	-	B	-	B	-	A	A	A	B	A	A	D	A	-	-	D	
Fruit Juice	A	A	B	A	-	-	A	A	B	-	-	A	A	-	-	B	D	B	-	A	A	A	A	A	-	-	-	B	A	-	-
Fuel Oils	A	B	D	A	-	-	A	A	A	A	A	A	-	-	-	B	-	A	-	A	A	A	A	A	B	A	D	D	A	-	-
Furan Resin	A	-	-	-	-	A	-	-	A	A	-	A	-	-	-	A	-	-	-	-	A	-	A	D	D	D	D	D	-	-	-
Furfural	A	D	D	D	D	A	A	D	B	A	A	A	-	-	-	A	-	A	B	A	A	-	D	D	D	D	D	D	-	-	-
Gallic Acid	-	-	-	A	-	-	A	-	-	-	-	A	-	-	-	A	-	A	A	-	-	-	B	B	B	B	B	A	-	-	A
Gasoline	A	C	D	C	D	A	A	D	A	A	A	A	-	-	-	A	A	A	A	-	-	-	B	B	B	B	B	A	-	-	-
Gelatin	A	A	-	A	-	-	A	A	A	-	-	A	-	-	-	A	D	A	A	A	A	-	A	A	A	A	A	A	-	-	-
Glucose	A	A	B	A	B	A	A	B	A	-	-	A	-	-	-	A	B	A	-	-	A	-	A	A	A	A	A	A	-	-	B
Glue P.V.A.	A	-	-	-	-	-	A	-	A	-	-	A	B	-	-	A	-	B	-	-	A	-	A	A	A	-	-	-	-	-	B
Glycerine	A	A	-	A	C	A	A	A	A	-	-	A	A	-	-	A	B	A	A	-	-	-	A	A	A	A	A	A	-	-	B
Glycolic Acid	A	A	B	A	-	-	-	-	C	A	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	-	-	-	-	-	-
Gold Monocyanide	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	D	-	-	-	-	-	A	A	A	-	-	-	-	-	-
Grape Juice	A	-	B	A	B	A	-	A	B	-	-	A	A	-	-	B	D	B	-	A	A	-	A	A	A	-	-	A	-	-	-
Grease	A	-	-	-	-	-	A	-	A	-	-	A	-	-	-	B	-	A	-	-	-	-	A	A	D	D	-	B	-	-	-
Heptane	A	D	D	A	C	-	D	A	A	A	-	-	-	-	-	B	-	A	A	A	-	-	A	A	B	A	-	-	-	-	-
Hexane	A	C	-	C	D	-	A	D	A	A	A	A	-	-	-	B	-	A	A	A	-	-	A	A	B	A	D	B	-	-	-
Honey	A	A	-	-	B	-	A	A	A	-	-	A	-	-	-	A	A	A	-	-	-	-	A	A	A	A	A	A	-	-	-
Hydraulic Oils (Petroleum)	A	D	-	-	-	-	A	-	A	-	-	A	-	-	-	B	A	A	-	-	-	-	A	A	C	B	D	B	A	-	-
Hydraulic Oils (Synthetic)	A	D	-	-	-	-	A	-	A	-	-	A	-	-	-	A	A	A	-	-	-	-	A	C	B	D	B	A	-	-	-
Hydrazine	A	-	-	-	-	-	A	-	A	-	-	A	-	-	-	-	C	-	-	-	-	-	A	B	B	B	C	B	A	-	-
Hydrobromic Acid 20%	B	A	-	A	-	-	D	A	-	-	-	A	-	-	-	-	-	-	-	-	-	-	A	D	C	-	-	-	-	-	-
Hydrobromic Acid	A	B	B	A	-	-	D	C	D	-	-	A	D	D	D	A	D	D	D	A	A	-	A	D	D	D	A	A	-	-	B
Hydrochloric Acid (Dry Gas)	A	-	-	A	-	-	-	-	-	-	-	A	C	-	-	-	-	D	A	A	-	-	-	-	-	-	C	-	C	A	B
Hydrochloric Acid (20%)	A	A	A	A	B	A	D	A	D	A	A	D	D	D	C	D	D	D	B	A	A	D	A	C	C	A	B	C	B	A	B
Hydrochloric Acid (37%)	A	A	A	A	C	C	D	A	D	A	D	D	D	D	C	D	D	D	B	A	A	D	A	B	B	B	B	A	-	-	B
Hydrochloric Acid 100%	A	-	A	A	-	-	D	-	-	-	-	A	D	D	-	D	D	D	C	A	A	-	A	D	D	D	D	D	-	-	A
Hydrocyanic Acid	A	A	B	A	-	-	A	A	B	-	-	A	A	A	C	-	D	-	A	A	A	-	A	B	B	B	B	A	-	-	B
Hydrocyanic Acid (Gas 10%)	A	-	-	A	-	-	-	-	-	-	-	A	D	D	-	-	-	-	-	-	-	-	-	-	-	C	-	C	-	-	-
Hydrofluoric Acid (20%)	B	A	C	D	-	-	D	A	D	A	A	D	D	D	D	D	D	D	B	B	C	D	A	D	C	C	C	-	-	-	B
Hydrofluoric Acid (50%)	C	D	C	C	-	-	D	C	D	A	A	D	D	-	D	D	D	D	B	D	D	D	A	D	C	-	C	-	-	-	B
Hydrofluoric Acid (75%)	C	D	D	D	-	-	D	D	D	A	A	D	D	-	D	D	D	D	B	D	D	-	A	D	D	-	D	-	-	-	C
Hydrofluoric Acid 100%	A	-	A	C	-	-	-	-	-	-	-	A	D	D	-	D	D	D	B	D	D	-	-	D	D	-	D	-	-	-	D
Hydrofluosilicic Acid (20%)	C	A	-	D	-	-	D	B	D	-	-	A	D	D	-	D	A	D	B	A	D	-	A	B	B	A	A	-	-	-	-
Hydrofluosilicic Acid	-	-	-	-	-	B	-	-	-	-	-	A	D	D	-	D	-	C	C	A	-	-	A	B	B	B	A	A	B	C	-
Hydrogen Gas	A	-	-	A	-	-	-	-	-	-	-	A	-	-	-	-	-	A	-	-	-	-	A	A	A	A	B	A	-	-	-
Hydrogen Peroxide 10%	D	-	A	A	-	-	D	-	-	B	A	C	C	-	C	D	D	A	A	A	-	-	A	D	-	C	-	-	-	-	A
Hydrogen Peroxide 30%	B	A	-	A	-	-	D	-	-	C	A	B	-	-	B	-	-	-	-	-	-	-	A	D	C	-	-	-	-	-	B
Hydrogen Peroxide 50%	-	-	-	B	-	-	D	-	-	C	A	B	-	-	-	-	-	-	A	-	-	-	A	D	C	-	-	-	-	-	-
Hydrogen Peroxide	A	A	B	A	-	-	D	D	B	D	C	A	B	A	-	-	-	-	A	-	-	-	A	B	B	B	B	B	A	C	-
Hydrogen Sulfide, Aqueous Solution	A	A	B	A	-	-	D	A	D	A	A	A	A	C	-	-	-	-	A	-	-	-	A	D	D	B	D	D	C	-	B
Hydrogen Sulfide (Dry)	A	-	-	A	-	-	A	D	-	-	A	A	A	C	-	-	-	-	A	-	-	-	D	D	B	D	D	C	A	-	-
Hydroxyacetic Acid (70%)	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	B	-	-	-	-	-	-	A	A	A	-	-	-	-	-	-
Ink	A	-	B	-	-	-	-	B	A	-	-	A	A	-	-	C	D	C	-	-	-	-	A	A	-	-	-	-	-	-	-
Iodine	A	D	D	D	D	-	D	A	C	-	-	A	D	D	D	A	D	D	B	D	A	-	A	B	D	B	D	B	A	B	-
Iodine (In Alcohol)	-	B	-	D	-	-	D	C	-	-	-	A	B	-	-	-	-	-	-	-	-	-	A	D	-	-	-	-	-	-	-
Iodoform	-	-	-	-	-	-	A	-	-	-	-	A	A	D	-	-	-	-	-	-	-	-	C	-	-	-	-	-	-	-	-
Isotane	A	D	-	-	-	-	D	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	-	-	-	-	-	-	-
Isopropyl Acetate	A	-	-	-	-	-	-	-	A	-	-	B	-	-	-	-	-	-	C	-	-	-	D	D	D	D	D	D	-	-	-
Isopropyl Ether	-	D	-	-	-	-	D	A	-	-	-	A	-	-	-	-	-	-	A	-	-	-	D	B	C	B	D	C	-	-	-
Jet Fuel (JP3, JP4, JP5)	A	D	-	A	-	-	A	D	A	A	-	A	-	-	-	-	-	-	A	-	-	-	A	A	D	-	D	-	-	-	-
Kerosene	A	D	D	A	B	A	A	D	A	A	A	A	A	-	-	-	-	-	A	-	-	-	A	A	C	A	D	D	-	-	-
Ketones	C	D	D	D	-	-	A	A	D	B	A	A	A	-	-	-	-	-	B	A	C	-	D	D	D	-	C	-	-	-	D
Lacquers	A	A	-	-	-	-	A	A	C	A	-	-	A	-	-	-	-	-	A	-	-	-	D	D	D	D	D	D	-	-	D
Lacquer Thinners	-	B	-	C	-	-	A	D	-	-	-	A	-	-	-	-	-	-	-	-	-	-	D	D	D	D	D	D	-	-	D
Lactic Acid	A	A	B	A	-	-	C	A	B	A	A	B	A	C	A	D	D	C	A	-	-	-	A	A	A	A	A	A	-	-	B
Lard	A	A	-	A	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	C	A	D	D	-	-	-
Latex	A	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	C	A	-	-	-	-	-
Lead Acetate	A	A	B	A	-	-	A	A	A	-	-	A	A	-	-	A	C	-	D	A	A	-	D	B	B	B	A	D	-	-	B
Lead Sulfamate	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	B	A	B	B	A	-	-	-
Ligroin	A	D	-	-	-	-	D	A	-	-	-	A	-	-	-	-	-	-	-	-	-	-	A	A	B	A	D	C	-	-	-
Lime	A	-	-	A	C	-	-	A	D	-	-	A	-	-	-	-	-	-	-	-	-	-	A	A	B	A	A	B	-	-	-
Lubricants	A	A	-	A	B	A	A	-	A	A	A	A	-	-	-	A	B	-	A	A	A	-	A	A	B	A	D	D	-	-	-
Magnesium Carbonate	A	A	B	A	-	-	-	A	A	-	-	A	A	-	-	-	-	-	B												

GROUND WATER SAMPLING, INC.
1855 V. UNION, SUITE B-5
ENGLEWOOD, COLORADO 80110

	EPOXY	POLYPROPYLENE	POLYETHYLENE	PVC (Type 1)	CYCOLAC (ABS)	PHENOLIC	NYLON	NORYL	POLYACETAL	RYTON 200°F	TEFLON	STAINLESS (316)	STAINLESS (304)	STAINLESS (440)	TITANIUM	CAST BRONZE	CAST IRON	ALUMINUM	HASTELLOY C	CARBON CERAMIC S	CERAMIC	CERAMAGNET "A"	VITON	BUNA N	NEOPRENE	NITRILE	RUBBER (Nat.)	HYALON	KEL-F
Mercury	A	A	B	A	-	-	A	A	A	-	A	A	A	A	C	D	A	C	A	A	-	A	A	A	A	A	A	A	-
Methanol (See Alcohol Methyl)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methyl Acetate	-	-	-	-	D	-	-	-	A	-	-	-	-	-	-	A	-	A	A	A	A	-	D	D	B	D	D	D	-
Methyl Acrylate	A	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	D	D	B	D	D	D	-
Methyl Acetone	C	-	-	-	-	-	-	D	A	-	-	-	-	-	-	A	-	A	-	-	-	-	-	D	D	-	-	-	-
Methyl Alcohol 10%	A	-	-	A	-	-	-	-	-	-	A	-	-	-	-	C	-	C	A	-	-	-	-	A	B	D	B	D	-
Methyl Bromide	B	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	D	D	D	D	D	-
Methyl Butyl Ketone	B	-	-	-	-	-	-	-	D	B	-	-	-	-	-	-	-	-	-	-	-	-	-	D	D	D	D	D	-
Methyl Cellosolve	C	A	-	-	-	-	-	-	C	B	-	-	-	-	-	A	-	A	-	-	-	-	D	C	B	C	D	D	-
Methyl Chloride	A	D	D	D	-	-	A	D	A	-	A	A	C	-	A	A	-	D	A	A	A	-	A	D	D	D	D	D	A
Methyl Dichloride	A	-	-	-	-	-	-	D	A	-	-	-	-	-	-	-	-	-	-	-	-	-	A	D	D	-	D	-	-
Methyl Ethyl Ketone	B	A	D	D	D	A	A	D	B	A	A	A	-	-	A	A	-	A	A	A	A	-	D	D	D	D	D	D	-
Methyl Isobutyl Ketone	B	C	-	D	D	A	A	D	B	A	A	-	-	-	A	-	-	-	-	-	-	-	D	D	D	D	D	D	-
Methyl Isopropyl Ketone	B	-	-	-	-	A	A	D	B	-	-	-	-	-	-	-	-	-	-	-	-	-	D	D	D	D	D	D	-
Methyl Methacrylate	A	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	D	D	D	D	D	D	-
Methylamine	A	-	-	-	-	-	-	B	D	-	-	A	-	-	-	D	-	-	-	-	-	-	-	B	-	-	-	-	-
Methylene Chloride	A	D	D	D	-	A	D	D	A	-	A	A	-	-	A	A	-	A	A	A	A	-	B	D	D	D	D	D	-
Milk	A	A	B	A	B	-	A	A	A	-	-	A	A	-	-	C	D	A	A	A	A	-	A	A	A	A	A	-	-
Molasses	A	A	B	A	-	-	A	B	A	-	-	A	A	-	-	-	-	-	-	-	-	-	A	A	A	A	-	-	-
Mustard	A	A	-	-	B	-	A	B	B	-	-	A	A	-	-	B	C	B	-	-	-	-	A	B	A	C	A	A	A
Naphtha	A	A	D	A	C	A	A	D	A	A	A	A	A	-	A	B	B	A	A	A	A	-	A	C	D	C	D	D	-
Naphthalene	A	B	D	D	-	A	-	D	A	A	A	B	A	-	A	C	B	B	A	A	A	-	C	D	D	D	D	D	-
Nickel Chloride	A	A	B	A	-	A	A	A	B	-	A	B	A	-	A	D	D	D	A	A	A	-	A	A	B	A	A	A	-
Nickel Sulfate	A	A	B	A	-	C	A	A	B	-	A	B	A	-	A	C	D	D	B	A	A	-	A	A	A	A	C	B	A
Nitrating Acid (15% H ² SO ⁴ or less)	-	-	-	-	-	D	-	-	-	-	A	C	-	-	A	D	-	D	A	A	-	-	-	-	-	A	C	-	-
Nitrating Acid (15% H ² SO ⁴ or more)	D	-	-	-	-	-	-	-	-	-	A	C	C	-	C	D	A	D	A	D	A	-	-	-	-	C	C	-	-
Nitrating Acid (1% Acid or less)	-	-	-	-	-	-	-	-	-	-	A	A	C	-	-	D	-	D	A	D	A	-	-	-	-	-	C	-	-
Nitrating Acid (15% HNO ³ or less)	-	-	-	-	-	-	-	-	-	-	A	D	C	-	-	C	D	-	D	A	D	-	-	-	-	-	C	-	-
Nitric Acid (5-10% Solution)	A	A	B	A	C	D	D	A	D	A	A	A	A	-	A	D	D	D	A	C	B	D	A	D	D	-	D	-	-
Nitric Acid (20% Solution)	B	A	B	A	D	D	D	A	D	C	A	A	A	-	A	D	D	D	A	D	C	D	A	D	D	-	D	B	A
Nitric Acid (50% Solution)	D	D	C	A	D	D	D	A	D	D	A	A	A	-	A	D	D	D	A	D	A	-	C	D	D	D	D	-	-
Nitric Acid (Concentrated Solution)	D	D	D	D	D	D	D	D	D	D	A	B	D	-	A	D	D	B	B	D	A	C	D	D	D	D	D	D	-
Nitrous Acid	-	-	-	-	-	-	-	-	-	-	A	A	-	-	-	A	-	-	-	-	-	-	-	-	D	-	C	-	-
Nitrobenzene	B	C	D	D	D	-	C	D	B	A	A	B	A	-	A	D	-	C	B	A	A	-	B	D	D	D	D	D	-
Oils	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aniline	A	A	-	D	D	A	C	D	D	-	A	A	-	-	A	A	A	C	D	A	A	-	C	D	D	D	D	D	-
Anise	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-	-	-
Bay	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-	-	-
Bone	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	A	A	D	A	-	-
Castor	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	A	-	-	-	-	-	-	-	A	A	A	A	-	-
Cinnamon	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	D	-	-	-
Citric	A	A	-	-	-	A	A	-	A	-	-	A	-	-	-	D	D	-	-	-	-	-	A	A	D	-	-	-	-
Clove	A	B	-	-	-	A	A	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Coconut	A	A	-	-	-	A	A	-	A	-	-	A	-	-	-	A	A	B	-	-	-	-	-	-	-	-	-	-	-
Cod Liver	A	A	-	-	C	A	A	-	A	-	-	A	-	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-
Corn	A	A	-	-	C	A	A	-	A	-	-	A	-	-	-	B	A	B	-	-	-	-	-	-	-	-	-	-	-
Cotton Seed	A	A	-	A	C	A	A	-	A	-	-	A	-	-	-	B	A	B	-	-	-	-	-	-	-	-	-	-	-
Cresote	A	D	-	-	-	A	-	-	D	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diesel Fuel (2D,3D,4D,5D)	A	A	-	-	-	A	A	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fuel (1,2,3,5A,5B,6)	A	B	-	A	-	A	-	D	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ginger	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydraulic (See Hydraulic)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lemon	A	D	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Linseed	A	A	-	A	C	A	A	-	A	-	-	A	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-
Mineral	A	B	-	A	-	A	A	B	A	-	-	A	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-
Olive	A	A	-	A	-	A	A	-	A	-	-	A	-	-	-	B	A	A	-	-	-	-	-	-	-	-	-	-	-
Orange	A	A	-	-	-	A	A	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palm	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-
Peanut	A	D	-	A	-	A	-	-	A	-	-	A	-	-	-	A	A	A	-	-	-	-	-	-	-	-	-	-	-
Peppermint	A	D	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pine	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	D	C	A	-	-	-	-	-	-	-	-	-	-	-
Rape Seed	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosin	A	A	-	-	-	A	A	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sesame Seed	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silicone	A	A	-	-	-	A	A	A	A	-	-	A	-	-	-	A	A	-	-	-	-	-	-	-	-	-	-	-	-
Soybean	A	A	-	A	-	A	A	-	A	-	-	A	-	-	-	B	A	A	-	-	-	-	-	-	-	-	-	-	-
Sperm	A	-	-	A	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanning	A	-	-	-	-	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turbine	A	-	-	A	C	A	-	-	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oleic Acid	A	C	D	A	B	-	A	C	B	-	-	A	-	-	-	B	C	B	B	-	-	-	-	-	-	-	-	-	-
Oleum 25%	D	-	-	D	-	-	-	D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oleum	A	D	-	D	-	-	-	D	-	-	-	A	-	-	-	C	-	B	-	-	-	-	-	-	-	-	-	-	-
Oxalic Acid (cold)	A	A	A	A	-	-	D	C	C	-	-	A	-	-	-	C	B	D	C	B	-	-	-	-	-	-	-	-	-
Paraffin	A	A	-	A	B	-	A	B	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pentane	A	-	-	-	D	-	-	D	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Perchloroethylene	A	D	-	-																									

Silicone	A	A	-	-	-	-	A	A	-	-	B	C	-	A	-	B	A	A	-	A	A	A	A	-
Silver Bromide	A	A	-	-	-	-	A	C	-	-	B	C	-	A	-	D	B	A	A	-	A	A	A	-
Silver Nitrate	A	A	B	A	-	A	A	C	-	A	A	B	A	D	D	D	B	A	A	-	A	C	A	C
Soap Solutions	A	A	B	D	-	-	A	A	A	A	A	A	A	B	B	C	A	A	A	-	A	A	A	B
Soda Ash (See Sodium Carbonate)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	A	A	A
Sodium Acetate	A	A	B	A	-	-	A	A	B	-	A	A	A	A	B	-	B	B	A	A	-	D	B	B
Sodium Aluminate	A	A	-	-	-	-	A	B	A	-	A	A	A	B	B	-	C	B	A	A	-	A	A	B
Sodium Bicarbonate	A	A	B	A	B	A	A	B	A	A	A	A	A	B	C	A	B	A	A	A	-	A	A	A
Sodium Bisulfite	A	A	B	A	C	A	C	A	B	A	A	A	A	A	C	D	D	B	A	A	-	B	A	A
Sodium Blausulfite	A	A	B	A	B	A	D	A	B	A	A	A	A	A	C	D	A	A	A	A	-	A	A	A
Sodium Borate	-	-	A	C	-	-	A	-	-	-	A	A	A	-	-	A	-	C	A	-	-	-	A	A
Sodium Carbonate	A	A	B	A	C	-	A	A	A	A	B	A	B	A	B	B	C	B	B	A	-	A	A	A
Sodium Chlorate	A	A	B	A	-	-	A	A	D	A	A	A	A	-	A	B	B	C	B	A	-	A	D	A
Sodium Chloride	A	A	B	A	B	A	A	A	A	A	B	A	C	A	B	B	C	B	A	A	-	A	A	A
Sodium Chromate	C	-	-	-	-	-	-	A	D	A	-	-	-	A	-	B	B	D	-	A	B	-	A	A
Sodium Cyanide	A	A	B	A	-	-	A	C	A	D	A	A	A	A	A	D	B	D	A	A	-	A	A	A
Sodium Fluoride	A	A	C	D	-	-	A	-	-	-	A	C	C	-	A	C	-	C	A	-	-	C	D	D
Sodium Hydrosulfite	A	A	-	-	-	-	A	-	-	-	A	-	-	-	A	C	-	A	-	-	-	A	-	A
Sodium Hydroxide (20%)	A	A	B	A	C	C	C	A	D	A	A	A	A	A	C	A	D	A	C	D	A	B	B	B
Sodium Hydroxide (50% Solution)	A	A	C	A	C	D	C	A	D	A	A	B	A	A	C	B	D	A	C	D	A	A	D	C
Sodium Hydroxide (80% Solution)	A	A	C	A	C	D	C	A	D	A	A	D	A	-	A	C	C	D	B	C	D	A	B	D
Sodium Hypochlorite (to 20%)	B	D	B	A	-	D	A	A	D	C	A	C	C	C	A	D	D	C	A	D	A	B	A	C
Sodium Hypochlorite	A	A	-	A	-	-	A	-	-	-	A	A	-	-	A	-	-	A	-	D	-	A	B	B
Sodium Hyposulfite	C	-	-	-	-	-	-	-	-	-	A	A	A	-	D	-	D	-	-	-	-	-	C	C
Sodium Metaphosphate	A	D	-	-	-	-	A	A	-	B	-	-	-	-	C	-	A	-	A	A	-	A	A	B
Sodium Metasilicate	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sodium Nitrate	A	A	B	A	-	-	A	A	B	-	A	A	A	A	B	A	A	B	A	A	-	A	B	B
Sodium Perborate	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sodium Peroxide	A	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sodium Polyphosphate (Mono Di, Tribasic)	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sodium Silicate	A	A																						

6

Table A I-3.

Resistance of well casing thermoplastics to common materials under expected use conditions* (after National Water Well Association and Plastic Pipe Institute, 1980).

	ABS	PVC	SR
Mineral Acids			
Hydrochloric (Muriatic) Acid-30%	+	+	+
Sulfuric Acid-50%	+	+	+
Sulfamic Acid-30%	+	+	+
Alkalies			
Ammonium Hydroxide-30%	+	+	+
Calcium Hydroxide-30%	+	+	+
Sodium Hydroxide-30%	+	+	+
Salts			
Calcium Chloride	+	+	+
Potassium Chloride	+	+	+
Sodium Bicarbonate	+	+	+
Sodium Chloride (Salt)	+	+	+
Sodium Phosphate	+	+	+
Sodium Sulfite	+	+	+
Oxidizing Agents /Disinfectants			
Sodium Hypochlorite (Bleach soln.)-12%	+	+	+
Chlorine Water	+	+	+
Calcium Hypochlorite-Soln.-18%	+	+	+
Organic Acids			
Acetic Acid-10%	+	+	+
Stearic Acid	+	+	+
Hydroxy Acetic Acid, 10%	+	+	+
Oils & Derived Products			
Crude Oil-Sour	+	+	+
Diesel Fuel	+	+	+
Gasoline	+	+	+
Lubricating & Thread Cutting Oils	+	+	-
Motor Oil	+	+	+
Solvents			
Acetone	-	-	-
Methyl Ethyl Ketone	-	-	-
Toluene	-	-	-
Trichloroethylene	-	-	-
Turpentine	-	+	-
Xylene	-	-	-
Soaps & Detergents	+	+	+
Gases			
Ammonia	+	+	+
Carbon Dioxide	+	+	+
Hydrogen Sulfide	+	+	+
Natural Gas	+	+	+
Oxygen	+	+	+

Key — + denotes resistant
- not resistant

For materials not included in the Table the well casing manufacturer should be consulted. An expanded table on chemical resistance of thermoplastic piping materials is also available from the Plastic Pipe Institute.

*The indicated extent of chemical resistance is for guidance purposes only for conditions of expected usage. As chemical resistance is influenced by stress, temperature and time of contact, this guidance is not necessarily applicable to all conditions.

APPENDIX II

APPENDIX II

General Groundwater Monitoring Requirements

1. All monitoring wells shall be cased in a manner that maintains the integrity of the monitoring well borehole. To enable collection of groundwater samples, this casing shall be screened or perforated and, where necessary, packed with gravel or sand. The annular space (i.e., the space between the borehole and well casing) above and below the sampling depth shall be sealed to prevent contamination of samples and of the groundwater.
 - a) The inside diameter shall be sized to facilitate the collection of samples.
 - b) The casing shall be constructed of a material which will not be reactive with or corroded by any leachate or contaminant.
 - c) PVC casing shall be joined in a manner which does not contribute organics to water samples.
 - d) The casing shall be screened or perforated in a manner that allows water to enter the well freely at low velocity, prevents sand from entering the well, and serves as the structural retainer to support loose formation material.
 - e) All monitoring wells shall be protected by a length of protective casing which is larger in diameter than the monitoring well casing and which extends below the land surface.
 - 1) The protective casing shall be grouted and placed with a protective collar to hold it firmly in position.
 - 2) The protective casing shall be identified by a highly visible color.
 - 3) The protective casing shall be higher above grade than the inner well casing.
 - 4) The protective casing shall have a vented cap that will allow the well to be secured against acts of vandalism.
 - f) All borings for monitoring wells shall be done by a technique that enables the well driller to obtain representative soil samples at 5-foot intervals.

- 1) The soil samples shall be placed in covered glass jars and labelled so that a stratigraphic log can be prepared.
 - 2) Sample jars containing soil samples shall be placed in the custody of the town or engineering firm after examination by an engineer or geologist and shall be available for inspection by the Department.
 - 3) When well clusters are used, soil sampling is only necessary at the deepest boring and at other borings at the screened depth.
- g) As technology changes in the field of groundwater monitoring, the Department may approve, in writing, different but equivalent or better methods for obtaining the information required to prepare a stratigraphic log, take water level measurements, or obtain representative groundwater samples.

APPENDIX III

Table A III-1. Suitability of sampling methods (after Gillham et al, 1983).

INORGANIC AND RADIOACTIVE PARAMETERS	Down-Hole Collection		Suction-Lift		Positive-Displacement			Gas-Lift	Gas-Drive	Jet-Pumps	Destructive-Sampling		
	Boilers	Depth-Specific Moons-nical	Boilers	Moons-nical	Centrifugal Pumps	Johnson-Rod	Platons Gas-Driven	Squeeze-Pumps			Coning-Extraction	Temporary Screened Augers	Installation Multiple Completion Wells
INORGANIC Contamination Parameters Electrical Cond. pH Redox Condition	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
Non Toxic Constituents Chloride Sulfate Sodium Ammonium Calcium, Magnesium Iron, Manganese	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
Toxic Constituents Nitrate Fluoride Arsenic Selenium Barium Cadmium Chromium Lead Silver Mercury	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
RADIOACTIVE Radium Gross Alpha and Beta	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)
	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	S (L) (L)	(U) (L) (L)	S (L) (L)	S (L) (L)	(L) (L) (U)

Key: S: Suitable
 L: Limited suitability; can be used for qualitative or approximate information
 U: Unsuitable
 (): Procedural modifications can be used to improve suitability to next level

BIOLOGICAL AND ORGANIC PARAMETERS	Down-Hole Collection		Suction-Lift		Positive-Displacement			Gas-Lift	Gas-Drive	Jet-Pumps	Destructive-Sampling	
	Bailers	Depth-Specific Mechanical Pneumatic	Suction on liquid phase	Suction on gas phase	Centrifugal Pumps Conventional	Johnson- Keok	Piston Rod Driven	Squeeze- Pumps			Coring- Extraction	Temporary Screened Multiple Com- pletion Wells
BIOLOGICAL Coliform Bacteria	S	(L)	S	(L)	L	(L)	U	(L)	(U)	(U)	S	(L)
	(L)	S	S	L	(L)	(L)	U	S	S	U	S	(L)
ORGANIC Drinking-Water Stds. Endrin Lindane Methoxychlor Toxaphene 2,4-D 2,4,5-TP Silver												
Quality Parameters Phenols												
Contamination Parameters Total Organic Carbon Total Organic Halogen	(L)	(L)	S	(U)	(L)	(L)	U	(L)	(L)	(U)	(U)	(L)
Gasoline Components Benzene Toluene Xylene Methyl t-butyl ether												

Key: S: Suitable
 L: Limited suitability; can be used for qualitative or approximate information
 U: Unsuitable
 (-): Procedural modifications can be used to improve suitability to next level

Table A III-2. Potential sources of bias (after Gillham et al, 1983).

INORGANIC AND RADIOACTIVE PARAMETERS	DIRECT	INDIRECT
INORGANIC Contamination Parameters Electrical Cond. pH Redox Condition	temperature, suspended particles, precipitation, adsorption / exchange CO ₂ degassing, precipitation of carbonates and oxides	degassing, change in Eh, pH O ₂ invasion, temperature, microbial activity
Non Toxic Constituents Chloride Sulfate Sodium Ammonium Calcium Magnesium Iron, Manganese	contact with skin precipitation of gypsum, reduction adsorption / exchange, leaching from glass, contact with skin adsorption / exchange, volatilization at low pH adsorption / exchange adsorption / exchange, precipitation	- - - - CO ₂ degassing O ₂ invasion, CO ₂ degassing
Toxic Constituents Nitrate Fluoride Arsenic Selenium Barium Cadmium Chromium Lead Silver Mercury	denitrification, nitrification precipitation adsorption / exchange / leaching from sampling equipment, precipitation	- - CO ₂ degassing, O ₂ invasion
RADIOACTIVE Radium Gross Alpha and Beta	adsorption / exchange, precipitation, degassing	

* Cross-contamination is a problem for all parameters, but is indicated here as a source of bias only if it is especially likely to occur.

BIOLOGICAL AND ORGANIC PARAMETERS	DIRECT	INDIRECT
BIOLOGICAL Coliform Bacteria ORGANIC Drinking-Water Stds. Endrin Lindane Methoxychlor Toxaphene 2,4-D 2,4,5-TP Silvex	cross-contamination ^a sorption, cross-contamination ^a , biodegradation during storage	O ₂ invasion, pH, precipitation of other compounds
Quality Parameters Phenols	sorption, cross-contamination ^a , leaching, biodegradation during storage	
Contamination Parameters Total Organic Carbon Total Organic Halogen	sorption, cross-contamination ^a , leaching, volatilization, biodegradation during storage	O ₂ invasion
Gasoline Components Benzene Toluene Xylene Methyl t-butyl ether	sorption, cross-contamination ^a , leaching, volatilization, biodegradation during storage diffusion through plastics ^a] sorption, cross-contamination ^a , leaching, volatilization, biodegradation during storage	

^a Cross-contamination is a problem for all parameters, but is indicated here as a source of bias only if it is especially likely to occur.

Table A III-3. Summary of recommended sampling procedures
(after Gillham et al, 1983).

INORGANIC AND RADIOACTIVE PARAMETERS	POSSIBLE SOURCES OF BIAS	POSSIBLE MATERIALS THAT CAN CAUSE BIAS	POSSIBLE SAMPLING METHODS THAT CAN CAUSE BIAS	RECOMMENDED PRESERVATIVES AND/OR TREATMENT
INORGANIC Contamination Parameters Electrical Cond. pH Redox Condition	temperature, suspended particles CO ₂ degassing, O ₂ invasion O ₂ invasion, microbial activity	- - -	jet-pump gas-lift, jet-pump jet-pump	4°C, or field measurement field measurement
Non Toxic Constituents Chloride Sodium Sulfate Ammonium Calcium, Magnesium Iron, Manganese	skin contact skin contact, ads./exch./leaching from glass bypass precolp., microbial activity O ₂ invasion, pH, ads./exch. changes in Eh, pH before filtering	- glass - - soft or galvanized steel	jet-pump gas-lift, jet-pump	none 4°C field filter, HNO ₃ (pH2) field filter, 4°C, H ₂ SO ₄ (pH2) field filter, HNO ₃ (pH2)
Toxic Constituents Nitrate Fluoride Arsenic Selenium Barium Cadmium Chromium Lead Silver Mercury	microbial activity precolp. changes in Eh, pH before filtering, ads./exch. on sample container	- - all metals PVC, PG, PP, all metals all metals	jet-pump gas-lift, jet-pump, conventional subsurface-pump	4°C none field filter, HNO ₃ (pH2)
RADIOACTIVE Radium Gross Alpha and Beta	changes in Eh, pH before filtering, degassing	- -	gas-lift, suction-lift	- -

* SOURCE: U.S. Environmental Protection Agency (1978a)

BIOLOGICAL AND ORGANIC PARAMETERS	MOST LIKELY SOURCES OF BIAS	POSSIBLE MATERIALS THAT CAN CAUSE BIAS	POSSIBLE SAMPLING METHODS THAT CAN CAUSE BIAS	RECOMMENDED PRESERVATIVES AND/OR TREATMENT
BIOLOGICAL Coliform Bacteria	cross-contamination			
ORGANIC Drinking-Water Stds. Endrin Lindane Methoxychlor Toxaphene 2,4-D 2,4,5-TP Silvex	sorption, oxidation biodegradation	All, except: -teflon -stainless- steel -glass	gas-lift, jet-pump	4°C
Quality Parameters Phenols				4°C, H ₂ SO ₄ (pH2)
Contamination Parameters Total Organic Carbon Total Organic Halogen	volat., sorp., leaching		suction-lift, rod-pump, gas-lift, jet-pump, coring-extraction	4°C, H ₂ SO ₄ or HCl (pH2)
Gasoline Components Benzene Toluene Xylene Methyl t-butyl ether	volat., sorp., oxidation volat., sorp., diffusion volat., sorp., oxidation			4°C

• SOURCE: U.S. Environmental Protection Agency (1974a)

Table A III-4. Suitability of materials coming in contact with water samples (after Gillham et al, 1983).

INORGANIC AND RADIOACTIVE PARAMETERS	GROUTS AND SEALS			PLASTICS					METALS				GLASS	RUBBER
	Sand	Bentonite	Coarse	ABS	PVC	SR	PP	Teflon	Stainless Steel	Soft Steel	Galvanized Steel	Aluminum	Copper	Brass
INORGANIC Contamination Parameters Electrical Cond. pH Redox Condition	S	(L)	(U)	S	S	S	S	S	S	S	S	S	S	S
	S	(L)	(U)	S	S	S	S	S	S	S	S	S	S	S
	S	S	L ^a	S ^a	S ^a	(L)	S ^a	S	S	S ^a	S ^a	S ^a	S ^a	S ^a
Non Toxic Constituents Chloride Sulfate Sodium Ammonium Calcium, Magnesium Iron, Manganese	S	(L)	(L)	S	S	S	S	S	S	S	S	S	S	S
	S	(L)	(L)	S	S	S	S	S	S	S	S	S	S	S
	S	U	(U)	S	S	S	S	S	S	S	S	S	S	S
	S	U	(L)	S	S	S	S	S	S	S	S	S	S	S
	S	(U)	(U)	S	S	S	S	S	S	S	S	S	S	S
	S	(U)	(U)	S	S	S	S	S	S	S	S	S	S	S
	S	(U)	(U)	S	S	S	S	S	S	U	U	S ^a	S	S
Toxic Constituents Nitrate Fluoride Arsenic Selenium Barium Cadmium Chromium Lead Silver Mercury	S	L	L ^a	S	S	S	S	S	S	S	S	S	S	S
	S	L	L	S	S	S	S	S	S	S	S	S	S	S
	S	U ^a	L ^a	S	S	S	S	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L ^a	S	S	S	S ^a	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L ^a	S	S	S	S	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L ^a	S	S	S	S	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L	S	S	S	S	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L	S	U	S	U	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	U	L	S	S ^a	S	S ^a	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	(U) ^a	L	S	S ^a	S	S ^a	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	(U) ^a	L	S	S ^a	S	S ^a	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
	S	(U) ^a	L	S	S ^a	S	S ^a	S	(L) ^a	L ^a	L ^a	L ^a	L ^a	L ^a
RADIOACTIVE Radium Gross Alpha and Beta	S	L	L ^a	S	S	S	S	S	S	S	S	S	S	S
	S	L	L ^a	S	S	S	S	S	S	S	S	S	S	S

Key: S: Suitable
 L: Limited suitability; can be used for qualitative or approximate information
 U: Unsuitable
 (): Procedural modifications can be used to improve suitability to next level
 a: Suitability estimated due to lack of data

BIOLOGICAL AND ORGANIC PARAMETERS	GROUTS AND SEALS			PLASTICS					METALS					GLASS	RUBBER
	Sand	Bentonite	Cement	ABS	PVC	SR	PE	PP	Teflon	Stainless Steel	Soft Steel	Galvanized Steel	Aluminum			Copper	Brass
BIOLOGICAL Coliform Bacteria	S ^o	L ^o	L ^o	L ^o	L ^o	L ^o	L ^o	L ^o	S	S	L ^o	L ^o	L ^o	L ^o	L ^o
ORGANIC Drinking-Water Stds. Endrin Lindane Methoxychlor Toxaphene 2,4-D 2,4,5-TP Silvex															
Quality Parameters Phenols	S	L	L ^o	U ^o	L ^o	U ^o	U ^o	U ^o	S	S	L ^o	L ^o	L ^o	L ^o	U ^o
Contamination Parameters Total Organic Carbon Total Organic Halogen															
Gasoline Components Benzene Toluene Xylene Methyl t-butyl ether	S S	L ^o L ^o	L ^o L ^o	U ^o U ^o	U ^o U ^o	U ^o U ^o	U ^o U ^o	U ^o U ^o	S S	S S	L ^o L ^o	L ^o L ^o	L ^o L ^o	L ^o L ^o	U ^o U ^o

Key: S: Suitable
 L: Limited suitability; can be used for qualitative or approximate information
 U: Unsuitable
 (): Procedural modifications can be used to improve suitability to next level
 e: Suitability estimated due to lack of data

REFERENCES

- Barcelona, M., 1983. Chemical Problems in Groundwater Monitoring in Abstracts, Third National Symposium on Aquifer Restoration and Ground Water Monitoring. National Water Well Association. May 25-27.
- Benson, R. C., Glaccum, R. A., and Noel, M. R., 1982. Geophysical Techniques for Sensing Buried Wastes and Waste Migration. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. EPA, Las Vegas, Nevada, Contract No. 68-03-3050.
- Fisher, R. A., and Yates, F., 1947. Statistical Tables for Biological, Agricultural and Medical Research.
- Giddings, T., 1983. Bore Volume Purging to Improve Monitoring Well Performance: An Often Mandated Myth in Abstracts, Third National Symposium on Aquifer Restoration and Ground Water Monitoring. National Water Well Association. May 25-27, 1983.
- Gillham, R. W. and P. E. Johnson, 1981. A positive-displacement groundwater sampling device. Ground Water Monitoring Review, 1(3):33-35.
- Gillham, R. W., Robin, M.J.L., Barker, J. F., and Cherry, J. A., 1983. Groundwater Monitoring and Sample Bias. Environmental Affairs Department, American Petroleum Institute.
- Haan, C. T., 1977. STATISTICAL METHODS IN HYDROLOGY. Iowa State University Press, Iowa. p. 378.
- Kaufman, R. F., Gleason, T. A., Ellwood, R. B., Lindsey, G. P., 1981 Ground-water Monitoring Techniques For and Zone Hazardous Waste Disposal Sites, Ground Water Monitoring Review, V. 1, No. 3, pp. 47-54.
- Keely, J. F. and F. Wolf, 1983. Field Applications of Chemical Time-Series Sampling in Abstracts, Third National Symposium on Aquifer Restoration and Ground Water Monitoring. National Water Well Association. May 25-27.
- Keith, S. J., L. G. Wilson, H. R. Fitch, and D. M. Esposito, 1983. Sources of Spatial-Temporal Variability in Groundwater Quality Data and Methods of Control. Groundwater Monitoring Review. Spring, pp. 21-32.
- LeGrand, H. E., 1968. Monitoring of Changes in Quality in Ground Water. Groundwater 6, No. 3. pp. 14-18.
- Lohman, S. W., Bennet, R. R., Brown, R. H., Cooper, Jr., H. H., Drescher, W. J., Ferris, J. G., Johnson, A. I., McGuinness, C. L., Piper, A. M., Rorabaugh, M. I., Stallman, R. W., and Theis, C. V., 1972. Definitions of Selected Ground-water Items - Revisions and Conceptual Refinements, Geological Survey Water-Supply Paper, 21 pp.

- McCray, Kevin. "A Well Drilling Methods Primer", Water Well Journal, November 1981. pp. 45-47.
- Mendenhall, W., Ott, L. and R. L. Schaeffer, 1971. ELEMENTARY SURVEY SAMPLING. Duxbury Press. p. 247.
- Michigan Department of Natural Resources, Hydrogeologic Study Handbook, Water Quality Division (March 1982). 114 pp.
- Miller, D. W., 1981, Guidelines for Developing a Statewide Ground-water Monitoring Program: Groundwater Monitoring Review, Vol. No. 1, pp. 32-33.
- Nacht, S., 1983. Ground-water Monitoring System Considerations, Ground Water Monitoring Review, V. 3, No. 2, pp. 33-39.
- National Water Well Association and Plastic Pipe Institute, 1980. Manual on the selection and installation of thermoplastic water well casing. The National Water Well Association, Worthington, Ohio, and the Plastic Pipe Institute, New York, New York.
- Nelson, J. D. and R. C. Ward, 1981. STATISTICAL CONSIDERATIONS AND SAMPLING TECHNIQUES FOR GROUNDWATER QUALITY MONITORING, Groundwater Vol. 19, No. 6, pp. 617-625.
- Parizek, R. R., and Lane, B. E., Soil-Water Sampling Using Pan and Deep Pressure Vacuum Lysimeters, Journal of Hydrology, No. 11 (1970).
- Pettyjohn, W. A., 1976. Monitoring Cyclic Fluctuations in Groundwater Quality. Groundwater, V. 14, No. 6. pp. 472-480.
- Pettyjohn, W. A., Dunlop, W. J., Cosby, R., and Keeley, J. W.. Sampling Ground Water for Organic Contaminants, Groundwater, Vol. 19, No. 2, March-April 1981.
- Pettyjohn, W. A., 1982. Cause and Effect of Cyclic Changes in Ground-water Quality. Groundwater Monitoring Review, Winter, Vol. 2, No. 1, pp. 43-49.
- Pickens, J. F., Cherry, J. A., Grisak, G. E., Merritt, W. F. and B. A. Risto, 1978. A multi-level device for groundwater sampling and piezometric monitoring. Ground water 16(5):322-327.
- Ronen, D. and Kanfi, Y., 1981. Frequent Variations in the Chemical Quality of Groundwater - Monitoring Proglem. In: Quality of Groundwater, Proceedings of an International Symposium, Noordwijkerhout, The Netherlands. pp. 749-754.
- Rovers, F. A. and McBean, E. A., 1981. Significance Testing for Impact Evaluation. Ground Water Monitoring Review, Summer. pp. 39-43.
- Scalf, M. R., et al. Manual of Ground-Water Sampling Procedures, National Water Well Association, Worthington, Ohio, 1981. 93 pp.

- Selig, E. I., 1981. Rights and Liabilities of Water Suppliers Arising from Groundwater Pollution. Journal AWWA, April, Vol. (73), pp. 186-187.
- Stevenson, C. D., Simple Apparatus for Monitoring Land Disposal Systems by Sampling Percolating Soil Waters, Environmental Science and Engineering, 12, No. 3, pp. 329-331, 1978.
- Unwin, J. P., 1982. A guide to groundwater sampling. National Council of the Paper Industry for Air and Stream Improvement, Inc., Tech. Bul. 362, New York, New York.
- U. S. Environmental Protection Agency, 1977. Procedures manual for ground water monitoring at solid waste disposal facilities. Report EPA/530/SW-611.
- U.S. EPA, 1979. The Handbook for Analytical Quality Control in Water and Wastewater, EPA-600/4 -79-019.
- Walker, W., 1974. Field verification of industrial hazardous material migration from land disposal sites in humid regions. U. S. Environmental Protection Agency, July 1974.
- Wilkinson, W. B. and Edworthy, K. J., 1981. Groundwater Quality Monitoring Systems - Money Wasted? In: Quality of Groundwater, Proceedings of an International Symposium, Noordwijkerhout, The Netherlands. pp. 629-642.
- Zohdy, A. A. R., Eaton, G. P., and Mabey, D. R., Applications of Surface Geophysics to Ground-Water Investigations, U. S. Geological Survey, Techniques of Water-Resources Investigations, Book 2, Chapter D1 (U.S. Government Printing Office, 1974), 116 pp.

